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BLACK KNIGHT INSTRUMENTATION SYSTEMS

PART I MAIN BODY INSTRUMENTATION [C]

by

D. I. Dawton

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MINISTRY OF AVIATION
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SUMMARY

Details are given of the various instrumentation systems ~~used~~ in the main body of Black Knight test vehicles. Although existing guided weapon transducers were used for some measurements, emphasis is placed on the many special techniques which ~~were~~ developed specifically for this application. A brief description of optical tracking aids fitted to the rockets and an outline of the Upper-Atmosphere Research programme carried out is also included.

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1 INTRODUCTION

The Black Knight vehicle[1] was designed to gain experience in the problems associated with ballistic rocket flight and subsequent re-entry into the atmosphere. Investigation of propulsion, control and structural characteristics during the ascent of the vehicle together with the extremely important problems of re-entry heating and dynamics all provided requirements for the development of suitable instrumentation. Although it was possible to use or adapt existing guided weapon transducers for some measurements it was nevertheless necessary to develop a large number of special techniques specifically for the Black Knight programme and details are given in Parts 1 and 2 of this Report. The well established guided weapon equipment e.g. pressure transducers, accelerometers etc., is only briefly mentioned and greater emphasis is given to the special techniques which have been evolved.

The development of Black Knight instrumentation proceeded in three distinct phases. For the early proving vehicles (fitted with non-separating heads) the main emphasis was placed on determining the behaviour of guidance, control and propulsion systems until the propellents were "all-burnt". The second phase came with separating heads used for preliminary experiments at low re-entry velocities; the two-stage version of Black Knight introduced the third phase of development in which instrumentation was required for the second stage assembly and smaller high velocity (16000 ft/sec approx.) re-entry heads.

Details of the techniques developed for use in the main body of the vehicle are described in this Report and instrumentation systems for re-entry heads and second stage assemblies are given in Part 2.

2 DATA LINK

Information required from the main body (vehicle excluding the re-entry head or second-stage assembly, see Fig.1) until all propellents were used at a maximum altitude of about 80 miles, consisted principally of performance data from the guidance, control and propulsion systems. Although the effect of kinetic heating is not negligible, the velocity of the vehicle during ascent does not exceed the critical velocity at which ionisation effects become prohibitive and so it was possible to use R.F. telemetry links between the rocket and ground stations.

Calculations showed that a high power oscillator (approximate mean power output 6·5 watts) fitted in an R.A.E. 465 Mc/s telemetry transmitter would

provide adequate signal strength at the ground receivers throughout the propulsion phase and a useable signal (but intermittent due to the vehicle tumbling) up to the apogee altitude of about 450 miles. This system was therefore chosen to provide the data link with the main body of the vehicle.

The R.A.E. 465 Mc/s telemetry system can operate within the frequency range 440 to 480 Mc/s allowing up to three simultaneous transmissions with adequate separation of the carrier frequencies. The frequency modulator of each transmitter provides a sub-carrier which varies from 130 to 160 kc/s depending on input signal and a 24-channel sampling switch running at 85 c/s is used to transmit twenty-three inputs and one synchronisation pulse (186 kc/s). The modulator accepts both voltage and inductive inputs from transducers and the transmitters fitted in the main body of Black Knight vehicles were adjusted to give sub-carrier frequencies of 130 kc/s and 160 kc/s for inputs of +1·5 and -1·5 volts respectively. To increase the number of measurements which could be sampled, two motor driven six-pole six-way sub-commutation switches were developed for sampling quasi-static parameters at 1·5 samples/ second. (One for voltage and one for inductive transducer inputs.)

All telemetry components i.e. oscillator, modulator, sampling switch, sub-commutating switch (voltage inputs only) together with H.T. convertors, voltage calibration circuit etc., were built into a single unit which was fitted in the instrumentation compartment. This sender unit (Type TD 238) is shown in Fig.2 and is described in Ref.2. The sub-commutation unit for inductive transducers (Fig.3) was fitted in the motor bay because of the large number of pressure pick-offs used to monitor engine performance.

The R.F. output from telemetry senders was transmitted from special aerials (Fig.4) fitted to the instrumentation compartment of the vehicle (Fig.1(a)). The peak voltage on each aerial was about 600 volts and to prevent significant corona losses at high altitude a special type of open monopole aerial was developed by Radio Department, R.A.E. This design also provides a low drag, minimum weight installation which is not affected by kinetic heating during ascent.

Two telemetry senders and aerials were used to transmit body data from the early proving vehicles and about 50% of the later missiles. The remaining vehicles have been fitted with only one transmitter although a small telemetry unit fitted with a medium power oscillator (max. R.F. output 2 watts) has also been used occasionally to transmit vibration data and additional engine bay measurements. This sender is installed in a fin pod and has sufficient range to provide a data link during the first stage propulsion period.

3 TRANSDUCERS

For a large number of main body measurements it was possible to use standard G.W. instrumentation techniques developed specifically for the 465 Mc/s telemetry system and these are described briefly in Section 3.1. As the development of Black Knight proceeded many requirements arose for special measurements not covered by the standard range of guided weapon instrumentation. Section 3.2 and the following sections together with part 2 of this Report describes the instrumentation developed to meet these requirements.

3.1 Standard instrumentation

For measurement of the various guidance control and propulsion parameters it was possible to use mainly the existing G.W. range of accelerometers and pressure pick-offs. Accelerometers (Type TD 217) monitoring longitudinal, pitch and yaw acceleration were fitted in the telemetry unit located in the instrumentation compartment of the vehicle. Pressure transducers (Types G.W.2A and 3A etc.) monitoring the various pump inlet and outlet pressures, combustion chamber, steam turbine and hydraulic servo pressures were mounted in the motor bay. All the pressure pick-offs used were inductive, as there were no comparable transducers available with voltage outputs because of their weight and limited frequency response. Some problems occurred due to incompatibility of the standard range of transducers with H.T.P. propellent but these difficulties were overcome by fitting appropriate pressure transmitters and in one case (H.T.P. suction pressure) by designing a low pressure-range transducer compatible with H.T.P.

Many other measurements were directly available in electrical analogue form e.g. control system parameters, battery voltages etc. These quantities were monitored by providing potentiometer networks to supply the necessary voltage outputs to the telemetry transmitter, i.e. within the range ±1·5 volts.

3.2 Measurement of propellent level

To obtain optimum performance from the Black Knight vehicle it is important to ensure simultaneous depletion of both fuel and oxidant supply. Measurements of propellent consumption at sea level can be obtained from static firings but extrapolation to the flight condition is subject to error. It is therefore of considerable importance to monitor propellent consumption throughout flight so that corrections can be made on subsequent flights to the propellent loading conditions. The calibration of miniature flowmeters

is uncertain under high acceleration conditions and errors are integrated throughout flight. Development of a suitable propellent tank level sensor was therefore initiated.

Because a detailed description of the final system is given in Refs.3 and 4 only the salient features are given here. A basic limitation of the 465 Mc/s telemetry system is its overall accuracy which is approximately ±1% of full scale. This is inadequate for propellent level measurement and the method shown in Fig.5 was devised to extend the voltage scale of the telemetry modulator by a factor of 20. In this system an A.C. bridge is alternately balanced and unbalanced by the removal of elements of a sectionalized co-axial capacitor immersed in the propellent which acts as a dielectric. The scale of the telemetry modulator is increased by a factor equal to the number of elements and accurate measurements of propellent level are possible. The ultimate accuracy is determined in practice by the amplitude and frequency of fuel sloshing in the tank. The system is self calibrating because the changes in slope of the demodulated output (Fig.5) occur at definite levels in the tank and are independent of bridge sensitivity. By making the sections of unequal length it is also possible to code the output from the bridge so that the exact sensor element in use at any time can be determined from the flight record.

The technique described above was used in the kerosene tank of Black Knight vehicles and is suitable for short tanks where the co-axial capacitor can be supported satisfactorily e.g. for lengths of up to 5 ft (approx.). It was not considered possible to use this method in the Black Knight H.T.P. tank which is about 11 ft long and a number of capacity probes (usually six in number) were fitted in the tank wall. Although this system does not provide a continuous record it does give spot checks on H.T.P. consumption throughout flight. Both methods have provided valuable data on propellent consumption.

3.3 Temperature measurement

Data required from Black Knight vehicles during flight included air and chassis temperatures in the electronics bay and skin temperature at various positions on the missile. Estimates indicated that transducers would be required to operate in the ranges 10-100°C, 10-200°C and 10-300°C. The thermocouple was rejected because of its low voltage output and since the thermistor has a relatively long time constant[5] it was not considered acceptable for use with thin metal skins or for measuring air temperature. The resistance thermometer was therefore chosen as the most suitable transducer.

In the development of this instrumentation it was decided to employ a D.C. amplifier which had been designed for use with thermocouples in re-entry heads[6]. This unit provides an output of 3 volts for an input of 50 mV (at an impedance of less than 50 ohms) and it was used to amplify the output from a Wheatstone bridge (Fig.6) in which the variable resistance element was a resistance thermometer made from 0·001 inch diameter nickel wire.

The resistance of the wire is given as a function of temperature by the following well known approximation.

$$R_T = R_o[1 + \alpha T + \beta T^2 + \gamma T^3] \qquad (1)$$

where R_T = resistance at T°C
R_o = resistance at 0°C
T = temperature (°C).

For a typical sample of nickel wire

α = 0·0059 ohms/°C
β = $5{\cdot}5 \times 10^{-6}$ ohms/(°C)^2
γ = $1{\cdot}67 \times 10^{-8}$ ohms/(°C)^3.

The relationship between thermometer resistance and output impedance of the bridge circuit is given by

$$\text{Output impedance} = \frac{2P(1 + \delta)}{(3 + \delta)} \qquad (2)$$

where P resistance of each bridge element
and $\delta = \dfrac{\text{resistance of thermometer at T°C}}{\text{resistance of thermometer at 10°C}}$

The resistance of bridge elements 'P' and the thermometer at 10°C were chosen to be 33 ohm so that the output impedance of the bridge would always be less than 50 ohm, even at the maximum temperature of 300°C. The bridge is therefore balanced at 10°C and there is no voltage output. Although the resistance/temperature characteristic of the thermometer is appreciably non-linear (Fig.7) the overall bridge characteristic is approximately linear.

Bridge sensitivity can be varied according to the following expression by adjusting the series resistance R (Fig.6).

$$v = \frac{(\delta - 1)\,V}{(\delta - 1)\,\frac{R}{P} + 2\left(1 + \delta + \frac{R}{P}\right)} \qquad (3)$$

where v = voltage output from the bridge

V = bridge supply voltage.

This method was adopted to provide the three ranges 10-100°C, 10-200°C and 10-300°C so that a common bridge, resistance thermometer element and supply voltage could be used for each range. A 1·35 volt mercury cell energises each bridge and the value of series resistance R for each temperature range was determined from expression (3) so that at the maximum temperature the voltage output is 50 mV which is amplified to 3 volts by the telemetry pre-amplifier. Values of 'R' and estimates of the errors due to power dissipation in the resistance thermometers are given in Appendix A.

Each thermometer is wound so that its resistance at 10°C is 33 ohms ±0·1 ohm (approx. wire length 26 cm). Thermometers for measuring skin temperature, air temperature and temperature within a dummy explosive bolt are shown in Figs.8 to 10, and their construction is described briefly in Appendix B. A time lag of about 1·2 m sec is associated with elements attached to metal surfaces due to a thin sheet of mica insulation (0·0005 inch thick) which is used between the surface and element to prevent a short circuit.

Two calibration resistors are included in the bridge unit which is described in Appendix B. When connected in the place of a resistance thermometer they provide bridge outputs of about 25 mV (50% calibration) and 50 mV (100% calibration). These resistors are used to calibrate the bridge-amplifier combination so that any change in the overall characteristic during flight can be detected.

Early vehicles were fitted with three resistance thermometer channels 10-100°C, 10-200°C and 10-300°C each comprising four thermometers, a bridge unit and amplifier. The four thermometers and two calibration resistors associated with each bridge were switched in turn to form the variable resistance in the bridge circuit. Another contact shorted the input terminals of the amplifier between samples to suppress switching transients. The switches associated with all three channels were driven at about 1·5 c/s and the voltage from each amplifier was transmitted on a separate telemetry channel. Amplifier outputs were biased so that signals remained within the limits required to fully modulate the telemetry transmitter (±1·5 volts). A single resistance

thermometer channel is shown in Fig.11 and an overall voltage output/temperature characteristic for the 10-300°C range is shown in Fig.12. In later installations where only one temperature range was required (10-200°C) ten thermometers and two calibration resistors were sampled every 3 seconds (approx.) and transmitted on one telemetry channel.

Motor bay temperatures which exceeded 300°C were measured with thermocouples. Their voltage outputs were sampled, amplified by a D.C. amplifier[6] and transmitted on one telemetry channel. In a typical installation eleven thermocouple outputs and one calibration voltage were telemetered every 3 seconds (approx.). The cold junction of the thermocouples was encapsulated in Araldite resin to provide thermal insulation and its temperature was monitored by a resistance thermometer as already described.

3.4 Flap valve monitor

Eight "base bleed" holes about 6 inches in diameter are included in the skirt which encloses the motor bay of the Black Knight vehicle (Fig.1(a)). These allow air to enter the bay at low altitudes so that contamination by exhaust gases is avoided. For certain experiments designed to detect the pressurising effect of exhaust gases at high altitudes[7] it was necessary to fit flap valves to these ports and monitor their operation. Each aperture was covered by a rectangular plate carrying two hinged flap valves which opened into the motor bay. The doors were lightly loaded with springs which held them in the closed position providing the pressure within the bay did not fall below the external pressure. The positions of two valves in one quadrant of the engine bay were monitored but only the operation of one flap on each valve was telemetered because both flaps operate together. The capacity bridge developed for use with the kerosene level sensor (Ref.4 and Drg.No.GW.11070) was modified as an inductance bridge (Fig.13) and a steel stub was fitted to one flap of each valve so that as the door closed the steel core entered a small coil mounted inside the motor bay. The inductance of each coil changed from about 5 mH to 8 mH as the flap closed. The two coils were connected in series to form one arm of the inductance bridge (Fig.13 L.10 and L.11) which was energised at 50 kc/s. The output from the bridge was amplified and rectified to give a voltage which was transmitted on one channel of the telemetry system. The sensitivity of the bridge was adjusted so that if both valves were closed and then opened the voltage output to the telemetry changed from -0·7 to +0·7 volt. If one valve remained closed and the other open the output was about zero. Only three voltages were possible because the valves were either fully open or closed.

3.5 Donner accelerometer

After the initial proving trials with Black Knight it became apparent that the standard accelerometer (T.D.217) was not sufficiently accurate to give longitudinal acceleration data required to monitor engine performance. A search was made for an alternative transducer with better performance characteristics and the Donner accelerometer (Fig.14) was chosen for this application. The instrument is manufactured by the Donner Scientific Company of California and is of the force feedback type. Under the action of acceleration along its sensitive axis, a seismic mass in the instrument tends to move. An electro-mechanical servo provides a balance between the disturbing force proportional to acceleration and a restoring force proportional to the feedback current in a position restoring coil. The output from the accelerometer is provided by the voltage developed across a series resistor by the feedback current.

The advantage of this form of accelerometer, apart from its very high accuracy and sensitivity, is the dynamic range available from a current output system. The acceleration required to give full scale deflection of the telemetry system can be selected by a suitable choice of series resistor. The use of a simple potentiometer network enables outputs of high and low sensitivity to be obtained from one accelerometer.

The commonest arrangement used in Black Knight is shown in Fig.14 (System A). The calibration and bias unit includes the series resistor which is tapped to give full scale outputs for accelerations of 6g and 12g and because the modulator of the telemetry transmitter requires an input in the range ±1·5 volts a bias of -1·5 volts is provided. A voltage stabiliser within the unit provides the bias and calibration voltages for the telemetry channel which is used to transmit information from the Donner accelerometer.

System B (Fig.14) was used in two experiments to measure the effect of a thrust augmenter which was brought into operation during flight. This arrangement gives full scale deflection of the telemetry modulator for acceleration ranges of 4 to 5g (Channel I) and 4·6 to 5·6g (Channel II). This is achieved by applying bias voltages at the input terminals of D.C. amplifiers I and II and adjusting their voltage gains so that a change of 1g acceleration produces a change of 3 volts at their output terminals. Bias applied to the input of amplifier I is equivalent to an acceleration of -4·5g and the output is clipped so that it remains within the range ±1·5 volts required by the telemetry modulator. Amplifier II is connected in a similar

manner except that the bias applied to the input terminals is equivalent to an acceleration of $-5 \cdot 1g$. Systems A and B were both fitted in B.K.24.

Noise at the output of the Donner accelerometer due to vibration was experienced initially but this was overcome by using a suitable mounting and filter.

3.6 Turbine speed monitor

The object of this development was to telemeter the speed of the steam turbine which drives kerosene, H.T.P. and servo-oil pumps in the motor bay of Black Knight vehicles fitted with the gamma 301 engine. An overall accuracy of $\pm 0 \cdot 25\%$ was required from the instrumentation and telemetry system.

A tachometer generator driven through a reduction gear is used to monitor turbine speed during static firings. With the motor developing full thrust the turbine speed is approximately 54000 rev/min and the output frequency from the tachometer generator is about 182 c/s (0·7 volt rms). This signal could not be transmitted directly on one channel of the telemetry system because of bandwidth limitations and so the method shown in Fig.15 was adopted.

The sinusoidal voltage output from the tachometer generator is converted to a square waveform by a switching circuit. An eight-stage binary counter is used to count the number of positive pulses and trigger a linear sweep generator each time the total reaches 256. The voltage output from the unit is therefore a series of sawtooth pulses as shown in Fig.15. This is sampled about every 12 m sec by the telemetry switch and the time at which each linear sweep is initiated can be determined to an accuracy of ±1 m sec by interpolation on the telemetry record. At constant speed, the counter controls the time interval between successive output pulses and the count was chosen to give turbine speed to better than $\pm 0 \cdot 25\%$ at 54000 rev/min. The time interval between pulses is then approximately 1·4 seconds.

Turbine speed and the output frequency from the tachometer generator are related by the expression

$$\omega = 294 \cdot 8 \, f \qquad (4)$$

where ω = turbine speed (rev/min)

and f = output frequency from tachometer generator (c/s).

If the time interval between consecutive voltage pulses from the monitor unit is represented by 't' sec

$$f = \frac{256}{t} \text{ c/s}$$

therefore
$$\omega = \frac{75472}{t} \text{ rev/min} . \tag{5}$$

Expression (5) was used to plot the characteristic given in Fig.16 which shows the time interval between consecutive pulses as a function of turbine speed. The data gives mean turbine speed during intervals represented by 256 cycles from the tachometer generator i.e. about 1·4 sec for normal operation.

The turbine speed monitor unit is shown in Fig.18 and a circuit diagram is given in Fig.17. The design of the linear sweep generator was based on information given in Ref.8 and the voltage output was arranged to remain within ±1·5 volts required at the telemetry modulator.

3.7 Vibration measurement

The barium titanate vibration pick-off (type F) manufactured by G.E.C. was used to measure vibration in Black Knight vehicles. Measurements have been made during flight in the motor bay and instrumentation compartment of the main body. Cubes of duralumin (1·25 inch sides) were mounted at the positions of interest and three pick-offs were fitted to each block so that vibration was measured along three mutually perpendicular axes. A unit comprising three cathode followers was mounted adjacent to each block and the output from each pick-off was connected to a different cathode follower (input-impedance 20 megohms). A sampling switch in the motor bay connected the output from each cathode follower, in turn, to a 2 watt single-channel telemetry transmitter fitted in the Y.2 fin pod. (This sender provided the additional telemetry bandwidth required for vibration measurements.) The sampling switch made one revolution in 3 seconds and the output from each transducer was transmitted continuously for periods of 0·5 second.

3.8 Upper-atmosphere research experiments

Examination of the records from early firings indicated that sufficient power remained in the batteries supplying telemetry equipment to permit operation until the main body disintegrated at re-entry. The vehicle attitude after "all-burnt" was no longer stabilised and a random tumbling motion caused telemetry fades but data could be obtained for at least 50% of the

period from "all-burnt" to re-entry. As no further information was required from the body systems after the propulsion period, it was decided to use the telemetry link by fitting light-weight upper atmosphere research experiments which could be taken to altitudes of about 450 miles. The major limitations imposed on these experiments were as follows.

(a) The total weight was not to exceed 5 lb.

(b) Equipment could only be fitted where space was already available.

(c) Servicing was restricted to replacement and no testing was permitted during the final preparation phase of the vehicle.

Following consultations with University groups and Ministry Establishments a number of experiments were devised and ultimately installed in several Black Knight vehicles. The majority of the experiments were fitted in the separation bay (Figs.19 and 20) and a programme motor and relay assembly were used to energise the equipment and operate change-over switches which connected the voltage outputs to suitable telemetry channels at 10 seconds after nominal "all-burnt". In a typical three year period during the firing programme about thirty upper-atmosphere experiments were included in eleven vehicles with varying degrees of success. Details of these experiments are given in Appendix C.

4 OTHER INSTRUMENTATION

4.1 Flash units and detector

In addition to other sources of information an accurate measurement of the vehicle trajectory at "all-burnt" has been obtained, in several firings, by fitting the rocket with a marker flash system and launching the missile at night so that the flashes could be recorded on the plates of ballistic cameras located at suitable positions on the range. Velocity was also obtained from the trajectory data by using photomultiplier detectors on the ground to record the time at which each flash occurred. Since the photomultipliers have a limited field of view the time at which each flash occurred was also telemetered by using a missile-borne detector. The flash units and flash detector which have been fitted in the Y.2 fin pod of Black Knight vehicles are described in this section.

(a) Electronic flash unit

Very short and intense pulses of light can be obtained by discharging a capacitor through a gas-filled tube. This prinicple was employed in the electronic flash unit[9] to produce marker flashes at intervals of about

5 seconds. The unit was developed to give the following performance at an altitude of 200 miles so that flashes could be recorded until about three minutes after "all-burnt".

(i) A minimum light energy at ground level of $2 \cdot 6 \times 10^{-8}$ metre-candle-seconds.

(ii) A peak light intensity at ground level of 2×10^{-6} to 2×10^{-5} lumens/metre^2.

This ensured that a photographic image corresponding to a 6th magnitude star would be recorded by ballistic cameras and that the flash would trigger photomultipliers on the range.

The unit which is normally fitted in a sealed container is shown in Fig.21 with the cover removed. Eight 800 μf 500 volt electrolytic capacitors are charged and then connected to a gas discharge tube (Xenon) to give a flash having a duration of 270 μsec (approx.) a peak intensity of 10^7 candle power and an integrated light output of 2450 candle-second. An improved unit in which four special 2400 μf 500 volt annular condensers are fitted has also been developed and used successfully to provide trajectory data at higher altitudes.

(b) <u>Pyrotechnic flash unit</u>

Before the electronic flash unit became available pyrotechnic flashes were used to mark the trajectory. Up to eight cartridges (developed by Armament Department, R.A.E. and A.R.D.E. Langhurst) were fitted in a unit mounted in the Y.2 fin pod. Each pyrotechnic was self-contained and comprised the following:-

(i) Initiator.

(ii) Propellent to eject cartridge.

(iii) Time delay to clear vehicle.

(iv) Detonator.

(v) Main filling.

Cartridges were ejected at intervals of a few seconds controlled by a programme switch which began to operate shortly before "all-burnt". It was necessary for the light emitted by the pyrotechnics to exceed the output from the electronic flash unit by an adequate safety margin because a pyrotechnic burning in vacuo may only give about one quarter of the light output emitted at sea level. Experimental results obtained at sea level from five 'Type A'

cartridges (larger unit Fig.22) showed a mean total output of $7{\cdot}2 \times 10^5$ candle-sec ($5{\cdot}4 \times 10^5$ to $8{\cdot}6 \times 10^5$ candle-sec) a mean peak intensity of $10{\cdot}4 \times 10^7$ candles ($9{\cdot}9 \times 10^7$ to $11{\cdot}2 \times 10^7$ candles) a mean time interval to peak intensity of 3·3 m sec (2·6 to 4·0 m sec) and a total burning time of 36 m sec. The ejection velocity and time delay were arranged so that the flash ignited at a distance of about 20 ft from the vehicle. The cutters at the front of each cartridge (Fig.22) were intended to burst the diaphragm at the end of the cylindrical container when ejected. The complete unit (without cartridges) is shown in Fig.23.

The performance of the electronic flash unit is superior to the pyrotechnic unit because the number of flashes are not limited to about eight and the position of the vehicle is more accurately defined because

(i) the flash is not ejected

(ii) the time delay to peak light intensity is shorter.

(c) Flash detector

The flash detector unit (Fig.25) is only referred to briefly in this section because it is described in Ref.10. A Hilger and Watts FT425 photo-conductive cell is used in a detector circuit which generates a voltage pulse each time the photo-cell is illuminated by a flash from the missile-borne flash system. The pulse is used to trigger a linear sweep generator so that the output from the unit comprises a series of sawtooth voltage pulses of the form shown in Fig.24, where each pulse is caused by a flash. The maximum flash repetition rate which can be detected is approximately three flashes per second and since the time interval between successive flashes is about five seconds this is adequate. The output from the unit is sampled every 12 m sec by the telemetry switch and the time at which each pulse is initiated can be determined from the telemetry record to an accuracy of about ±1 m sec by interpolation. The voltage output from the detector is adjusted to remain within the range ±1·5 volts required to modulate the telemetry. The design of the linear sweep generator was based on data given in Ref.8.

4.2 Tracking lamps

The Gamma 201 engine which has been used in several Black Knight vehicles is not fitted with a mixture ratio control. If the kerosene supply is exhausted before the H.T.P. during flight "cold burning" occurs and the motor flame[11] can no longer be seen by the operator of the optical guidance telescope.. To overcome this tracking problem, lamps which provide a continuous light

output were fitted to B.K.07 and later vehicles. Each unit comprises a 26 volt 350 watt aircraft landing lamp (Air Ministry Ref. No.5L/2344) and a suitable reflector. Lamp units provide a light source of about 2200 candles when viewed along the longitudinal axis of symmetry through the filament and they are normally fitted to the P.1 and P.2 fins. When four fin pods are attached to the rocket (B.K.19 and B.K.24) a larger and more efficient reflector can be accommodated and the equivalent light source per unit is increased to 30000 candles. Even with the smaller light output, optical tracking is possible until about one minute after a normal engine flame-out.

5 CONCLUSIONS

Details have been given of the various instrumentation techniques developed for applications in the main body of Black Knight test vehicles. The systems described are, in general, the result of considerable laboratory and flight testing; a typical example is the kerosene level sensor which was tested in several different forms before a satisfactory version was produced. More detailed descriptions of the development problems associated with specific items of equipment can be found in individual system reports e.g. Refs.4, and 9.

Flight data obtained from the instrumentation has not been given in this Report. These can be found in the various papers on specific aspects of the Black Knight programme (e.g.Ref.12,13 and 14) and in Post-Firing Meeting reports.

One further point worthy of note is the reliability of the primary data handling equipment; for there have been no failures of the body telemetry system throughout the Black Knight programme. There have been some malfunctions in a few of the many transducers used with the telemetry senders, but in every firing satisfactory data transmission has been achieved.

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Appendix A

EFFECT OF POWER DISSIPATION IN A RESISTANCE THERMOMETER

The voltage output from the resistance thermometer bridge is directly proportional to the supply voltage (Section 3.3 expression (3)) but the power dissipation in the thermometer varies as the square of the energising voltage as follows

$$w_{max} = \frac{V^2}{(2P + R)(2P + 3R)} \tag{A.1}$$

where w_{max} = maximum power dissipated in the resistance thermometer throughout the temperature range.

This causes local heating at the thermometer and results in a false temperature reading. In the case of an air thermometer, the temperature rise ΔT caused by power dissipation w is given by the familiar expression

$$\Delta T = \frac{w}{\pi k\ JA} \tag{A.2}$$

where k = surface emissivity of wire

J = mechanical equivalent of heat

A = surface area of wire.

It was found experimentally that for an 80 cm length of 0·001 inch diameter nickel wire in air

$$\Delta T = 0{\cdot}072\ ^{\circ}C \text{ per mw}$$

so that

$$\Delta T = 5{\cdot}76\ \frac{w}{\ell} \tag{A.3}$$

where w = power dissipation (mw)

ℓ = length of wire (cm).

For skin thermometers bonded onto 0·015 inch thick aluminium alloy sheet the following empirical relationship was determined

$$\Delta T = 2{\cdot}6\ \frac{w}{\ell}\ . \tag{A.4}$$

Using a supply voltage of 1·35 volts the value of series resistance R for each temperature range was determined from expression (3) as explained in Section 3.3. The maximum power dissipation in the resistance thermometers and the corresponding temperature errors were then calculated from expressions (A.1), (A.3) and (A.4). The results are summarised in the following table and it is considered that the temperature errors are negligible.

Temp. range of bridge unit (°C)	Series resistance R (ohms)	Max. power dissipated in thermometer (mw)	Temperature error (°C)	
			Air thermometer	Skin thermometer
10 - 100	69·7	1·49	0·34	0·15
10 - 200	180·0	0·37	0·08	0·04
10 - 300	284·9	0·17	0·04	0·02

Appendix B

CONSTRUCTION OF RESISTANCE THERMOMETERS AND BRIDGE UNITS

(a) Skin thermometer

In its original form, nickel wire (0·001 inch diameter) was wound onto the adhesive surface of glass-fibre tape (Speedfix Type G.106). The sensitive element occupied an area of 0·5 inch x 0·5 inch and was covered by mica sheet (0·0005 inch thick) to provide an electrical insulation. The ends of the wire were spot welded to strips of nickel foil which passed through the tape to be anchored on the rear surface by a further layer of tape. The construction of a thermometer element of this type is shown in Fig.8 and when placed in position local heating (from a methylated spirits flame) was used to polymerise the adhesive and form a bond with the surface.

In some of the earlier firings difficulty was experienced in achieving a good thermal contact between the thermometer element and the metal skin and so the construction was modified by winding the nickel wire onto asbestos tape impregnated with Friedel-Craft resin, applying the mica insulation and then attaching the complete thermometer to the surface with Gow-Mac adhesive. This method of attachment is easy to effect and satisfactory up to 400°C (approx.) Skin temperatures of several Black Knight rockets have been measured by fitting thermometers of this type to the inside surface of the vehicles.

(b) Air thermometer

In this transducer the resistance wire is wound on two parallel nylon cords held between two spaced paxolin rings (Fig.9). Each turn of wire is anchored to the nylon by adhesive and the free ends are spot welded to nickel strips attached to terminals on the frame. The four bolts which hold the frame together are also used to mount the thermometer.

(c) Explosive bolt thermometer

This transducer was constructed to measure the temperature inside dummy explosive bolts fitted to proving vehicles which carried non-separating heads. The construction is similar to the early skin thermometers but the element occupies an area of 1·8 inches x 0·25 inch. Transformer paper (0·001 inch thick) insulates the element from the inside surface of the bolt (Fig.10) and a plastic rod which simulates the explosive charge holds the resistance thermometer firmly against the bolt. A similar thermometer was moulded in Araldite with the cold junction of each thermocouple installation to measure its temperature.

(d) Bridge units and batteries

Three 33 ohm resistors comprising the bridge, series resistor R and two calibration resistors were suitably interconnected and soldered to a plug which fitted a B7G valve base. The whole unit was then moulded in a cylindrical block of Araldite (length 1·5 inches, diameter 0·75 inch approx.) so that it could be plugged into an instrumentation tray. The bridge battery and bias battery required at the output of the telemetry pre-amplifier were moulded as another plug-in module fitted with a 12 way Belling-Lee unitor.

Appendix C

BLACK KNIGHT UPPER-ATMOSPHERE RESEARCH EXPERIMENTS

This Appendix comprises a brief description of the various upper-atmosphere research experiments which have been carried out with Black Knight rockets. The description includes a summary of the objectives together with some information on the experimental techniques.

Experiments are classified under the various research groups responsible for the design of equipment and these include four University groups together with W.R.E. (Australia) and R.A.E.

C.1 Imperial College, London

(a) Geiger counter experiment

The variation of cosmic ray intensity with altitude gives valuable information on the energy spectrum of primary cosmic rays. Above the atmosphere the so-called Störmer cone of allowed directions of arrival of primary particles of a given energy at a point inside the earth's magnetic field, varies in size with the altitude of observation. By monitoring the cosmic ray intensity during the ballistic flight of Black Knight, it is possible to determine the energy spectrum provided we take into account the altitude dependence of the Störmer cone and also the geometrical shadow of the earth. In addition, by monitoring cosmic ray intensity on a number of different flights it is possible to obtain data on long period variations in primary intensity.

It may be noted that at the peak altitude for Black Knight (325 or 450 miles for two and single stage versions) at the Woomera latitude the vehicle does not penetrate the Van Allen trapped radiation belts.

The equipment consists of a single halogen quenched geiger counter fitted with a lead shield to minimise the effect of varying the installation on different vehicles. The counter operates at 360 volts approximately, the EHT supply being derived from a transistorised EHT generator. The counter output pulses pass via a shaping amplifier and scaling unit to the telemetry for transmission to the ground. Power supplies are provided by Mallory cells in a potted battery pack.

(b) Cérénkov scintillation counter

This particular equipment was a prototype of a unit flown in the Scout satellite. The object of the Black Knight flight was to gain experience of

operating high voltage photomultiplier equipment in free space conditions and to provide basic calibration data on heavy nuclei cosmic ray primaries up to altitudes of 450 miles.

The primary cosmic rays in space comprise nuclei of atoms, mainly protons. Observations of cosmic ray protons at satellite altitudes are likely to be confused by protons trapped in the Van Allen radiation belt and the experiment was therefore designed to monitor the nuclei of heavier elements, carbon and upwards.

The equipment consists of a hollow plastic sphere approximately 4 inches in diameter and one-tenth of an inch thick on which is mounted a photo-multiplier tube. These are mounted in a light tight box in the separation bay of the vehicle. Energetic cosmic ray primary particles enter the plastic at velocities greater than the velocity of light in the plastic and as a result they produce "shock waves" of light by the Cérénkov effect. The sphere is coated with white paint which scatters the resulting flashes of light into the photomultiplier. The heavy primaries give a brighter flash than the protons and the photomultiplier output is therefore passed through a discriminator unit which permits only the 'heavy' pulses to pass through a scaling unit to the telemetry.

Power supplies are provided by a potted Mallory battery pack and the voltage for the photomultiplier is obtained from a transistorised EHT generator.

(c) Proportional counter experiment

This equipment was also a prototype of a unit flown in the Scout satellite. It was used to investigate fluctuations in the very low energy primary particles which are most affected by solar processes and it therefore extended the range of measurements below the minimum energy to which the Cérénkov counter responds.

The experimental arrangement consists of a proportional counter tele-scope having two independent sections between which different thicknesses of absorber can be interposed. Coincidence and bias levels were set to select protons of low energy as well as heavy primaries.

Once again the counter telescope, discriminators, coincidence units, scalers and power supplies were fitted in a light tight box in the separation bay of Black Knight.

C.2 University College, London

(a) Sporadic E measurements

This equipment was designed to measure the density profile of positive ions in the ionosphere with particular reference to detecting sporadic patches of enhanced ionisation in the lower E region. The equipment has been extensively flown in the Skylark rocket. It consists essentially of a negatively biassed probe assembly which attracts positive ions in the ionosphere. Measurement of the resulting positive ion current permits interpretation in terms of the ambient ion density. In order to resolve ambiguities in the output signal due to random motion of the vehicle after "all-burnt" either two or four equispaced probe assemblies were fitted around the separation bay of Black Knight.

The probe assembly is a 3 inch diameter polished flat plate probe and guard ring mounted on an access door on the separation bay. The probe is insulated with P.T.F.E. and the probe and ring are rhodium plated. The positive ion current passes via a single silicon transistor amplifier to telemetry. The power supplies and electronics are in a potted block mounted on the back of the probe assembly.

(b) Electron temperature

This experiment is similar to one flown in the Scout satellite. The object of the experiment is to measure the temperature of electrons in the ionosphere, i.e. their energy distribution. When particles are in equilibrium at a given temperature the distribution of energy amongst them has a characteristic form. If a probe electrode is in a plasma containing such an electron gas, then as the probe voltage varies the resulting current variation can provide a direct measure of electron temperature.

Using the normal Langmuir probe technique electron temperature is derived directly from the ratio of the first and second derivatives of the current-voltage curve. Previous workers have attempted to analyse the curve by double graphical differentiation of telemetered data but such a process does not give accurate results owing to poor signal/noise ratio at the receiver. The Scout equipment therefore used two voltages of different frequency applied to the probe giving a modulated waveform from which the first and second derivatives could be separated (using a variable gain tuned amplifier) and telemetered to the ground separately.

The equipment fitted to Black Knight consists of a probe assembly and the associated electronics and power supplies. The probe assembly is a 1 inch diameter polished flat plate probe and guard ring mounted on an access door on the separation bay. The whole assembly is rhodium plated and mounted flush to the vehicle skin. The waveform generator and amplifier are contained in two units mounted, together with the Mallory cell power supply, inside the separation bay.

(c) Positive ion mass spectrometer

There is considerable uncertainty about the nature of positive ions in the ionosphere. The object of this particular experiment (intended for satellite application) is therefore to determine the mass spectrum of positive ions. The velocity of Black Knight is much greater than the mean random velocity of the ions and it follows that the energy with which an ion impacts a probe on the vehicle is approximately $\frac{1}{2} Mv^2$ where M is the mass of the ion and v the velocity of the vehicle. A measure of the ion energy spectrum thus leads directly to the ionic mass spectrum. As in the case of the electron temperature experiment the energy spectrum can be determined by analysis of the current/voltage curve of a probe immersed in the ionised plasma.

For this experiment a spherical probe assembly is used, which for reasons of symmetry is insensitive to vehicle orientation provided the probe is mounted sufficiently far away from the vehicle "shadow". Because the electron current to such a probe would exceed the positive ion current it is desired to measure, the probe is surrounded by a negatively biassed spherical screening grid in order to repel electrons. This probe assembly is mounted on a long arm which is erected from inside the separation bay of the vehicle after the re-entry head has separated (see Fig.20).

The electronic equipment and power supplies for this experiment are similar to those fitted for the electron temperature experiment.

(d) Balloon experiment

One method of determining atmospheric density is to record the trajectory of an object of well defined drag/weight ratio e.g. a sphere. A proposal was originally made by University College to eject an inflated 3-foot diameter sphere from the Skylark rocket but a requirement by G.W. Department, R.A.E., for a reflecting target to act as a radar 'label' in certain Black Knight experiments, gave rise to a joint U.C.L./R.A.E. proposal for a 6-foot diameter inflatable balloon to be ejected from Black Knight. The R.A.E. radar requirement eventually lapsed but development of the balloon was completed and

both Skylark and Black Knight experiments have been made. The trajectory of the falling sphere can be monitored either by FPS16 radar (when within skin tracking range) or optically, in the case of astrotwilight firings, using the Baker Nunn camera or the several U.C.L. photo-electric trackers developed for range use.

The equipment installed in Black Knight is contained in a canister (15 inches x 5 inches diameter) mounted in the separation bay. A spring motor released by an electrically operated trigger after vehicle "all-burnt" ejects the sphere package and its attached filling bottle. Inflation of the metallised fabric sphere commences when a diaphragm is pierced at the instant the sphere package leaves the vehicle. The sphere is then separated from the bottle when the former is fully inflated. Separation is effected when a spring loaded mechanical release in the filling valve of the sphere is actuated by a cord running across the diameter of the sphere.

C.3 Manchester and Cambridge Universities

Galactic radio noise measurements

The object of this experiment is to investigate the spectrum of radio waves emanating from the Galaxy below a frequency of approximately 15 Mc/s. It is expected that much of the radiation at these frequencies will come from the roughly spherical 'halo' which surrounds our Galaxy. The disk of the Galaxy itself is probably relatively 'dark' because of absorption in ionised gas.

Signals below 15 Mc/s are severely attenuated by refraction in the ionosphere and hence little is known of their distribution from measurements below the ionosphere. A severe problem also exists due to earthbound sources radiating within this frequency band and producing interference at the receiver by reflection from the ionosphere. By carrying receiving equipment in a high altitude rocket these problems can be overcome, provided it is possible to erect a suitable receiving aerial system from the vehicle.

The equipment fitted in Black Knight can be conveniently considered under three headings:-

(a) Aerial unit (Manchester University)

The aerial consists of approximately 30 ft of steel tape coiled inside a drum and unreeled from the inside by a small electric motor. The aerial is extended after head separation and, when fully wound out, the motor is

switched off by a microswitch which also provides a signal to telemetry as proof of aerial extension.

Because of rotation of the vehicle the aerial will oscillate about its mean position under the influence of Coriolis and centrifugal forces. The rate of ejection (approximately 0·2 ft/sec) is sufficiently low to make these oscillations unimportant. The steel tape and the vehicle body together form an unbalanced dipole, short compared with one half wavelength and the aerial is therefore highly reactive. Directivity is rather poor and hence the spatial distribution of radio noise cannot be accurately determined.

The complete aerial assembly is contained in a unit fitted inside the separation bay, the aerial being ejected through a slot in the skin, in a direction roughly parallel to the vehicle major axis.

(b) Receiver unit (Manchester University)

Signals from the aerial are passed to the homodyne receiver unit also mounted in the separation bay. Because the possibility of station interference above the ionosphere cannot be ruled out at 5 Mc/s, the receiver switches periodically between two channels and in addition scans slightly on each channel. The central frequencies of the channels are approximately 4·9 and 4·1 Mc/s and the sweep bandwidths are 120 and 50 kc/s respectively. An internal noise source is also switched into the receiver periodically for calibration purposes. A simple diode detector provides an output to the telemetry transmitter.

(c) Receiver Unit (Cambridge University)

An alternative receiver unit, operating on a different principle can be fitted in the separation bay. In the Cambridge unit the superhet receiver (15 kc/s I.F. bandwidth) can be swept through the frequency range from 0·75 to 2·8 Mc/s.(7 second cycle period). A calibration oscillator signal is injected at 1·8 Mc/s. This receiver has a linear output for a 30:1 range of signal input.

As in the case of the Manchester receiver, this unit is mounted on a tray together with the necessary Mallory battery power supplies.

C.4 R.A.E. and W.R.E. experiments

(a) Controlled outgassing experiment

During early Black Knight firings large ionospheric disturbances were caused by the passage of the vehicle through the E and F layers of the ionosphere. These disturbances were detected by the H.F. radars operated at the Woomera range[14].

Various theories have been developed to explain the observed phenomena and it seems most likely that the effects are associated with the "outgassing" of small quantities of tank pressurisation gases together with expulsion of residual propellents from the thrust chambers. In order to obtain additional data an experiment was devised in which a known quantity of gas is ejected as the vehicle passes through the ionosphere and the effects are observed on the ground by H.F. radars.

The equipment was designed to fit in the Y.2 fin pod of the rocket. As the vehicle passes the 400 km level a programme switch operates a solenoid valve on a bottle containing about 1 lb of nitrogen at 3000 lb/in^2 and the gas is ejected in 5 seconds (approx.). Valve operation can be telemetered providing a channel is available. Experiments in which two or more discharges take place between altitudes of 300 and 500 km were also envisaged.

(b) Faraday rotation

To assist the analysis of H.F. radar data obtained during Black Knight flights through the ionosphere it was necessary to determine the electron density profile above the F region maximum. One method was to measure the Faraday rotation effect on the plane of polarisation of the signal received at the command-link equipment in the rocket.

For this experiment the circularly polarised command-link ground transmitter aerial is replaced at vehicle "all-burnt" by two plane polarised aerials (operating at different frequencies) so that it is possible to differentiate between the affect of vehicle motion and Faraday rotation. Signal strength at the two command-link receivers in the rocket is telemetered to provide the data required for analysis.

C.5 Installation programme and performance of equipment

A list of experiments fitted to Black Knight rockets during the period October 1959 to November 1962 is given in Table 1 and comments on the degree of success from the University experiments are given in Table 2.

Table 1

Upper-Atmosphere Research (Firing programme from Oct. 1959 to Nov. 1962)

Vehicle No.	06	07	08	09	10	11	12	13	14	15	16	17	18
Experiments													
Imperial College, London.													
(a) Geiger counter	✓	✓										✓	
(b) Scintillation counter		✓							✓	✓			
(c) Proportional counter											✓		
University College, London													
(a) Sporadic E		✓		✓						✓			
(b) Positive ion spectrometer								✓					✓
(c) Electron temperature									✓		✓	✓	
(d) Balloon experiment									✓				
Manchester and Cambridge Universities													
(a) Galactic radio noise													
(i) Cambridge receiver							✓	✓					
(ii) Manchester receiver												✓	
W.R.E./R.A.E.													
(a) Controlled outgassing						✓				✓	✓		✓
(b) Faraday rotation						✓	✓	✓	✓	✓	✓	✓	✓

Table 2

Performance of University experiments (Oct. 1959 to Nov. 1962)

Vehicle	Date fired	Height (miles)	Sponsor	Experiment	Results and comments
B.K.06	30/10/59	455	Imperial College	Geiger counter	Successful.
B.K.07	25/7/60	330	Imperial College	(1) Geiger counter (2) Scintillation counter	Initiation and telemetry changeover satisfactory; data obtained for complete flight. Results suspect owing to some form of interference.
			University College, London	Sporadic E probe	
B.K.09	21/6/60	301	University College, London	Sporadic E probe	Successful.
B.K.13	7/2/61	427	University College, London	Positive ion spectrometer	Electronic units switched on and telemetry changeover satisfactory at head separation but microswitch failure prevented deployment of spectrometer probe and receiver aerial.
			Manchester/Cambridge Universities	Radio noise (Cambridge receiver)	
B.K.14	9/5/61	260	Imperial College	Scintillation counter	Failure. No initiation of micro-switch assembly.
			University College, London	(1) Electron temperature (2) Balloon experiment	
B.K.17	7/6/61	362	Imperial College	Geiger counter	No data; microswitch failure.
			Manchester/Cambridge Universities	Radio noise (Manchester receiver)	No data; microswitch failure.
			University College, London	Electron temperature	Complete data throughout flight. Successful.
B.K.18	27/11/62	358	University College, London	Positive ion spectrometer	Data throughout flight. Successful.

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No.	Author	Title, etc.
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No.	Author	Title, etc.
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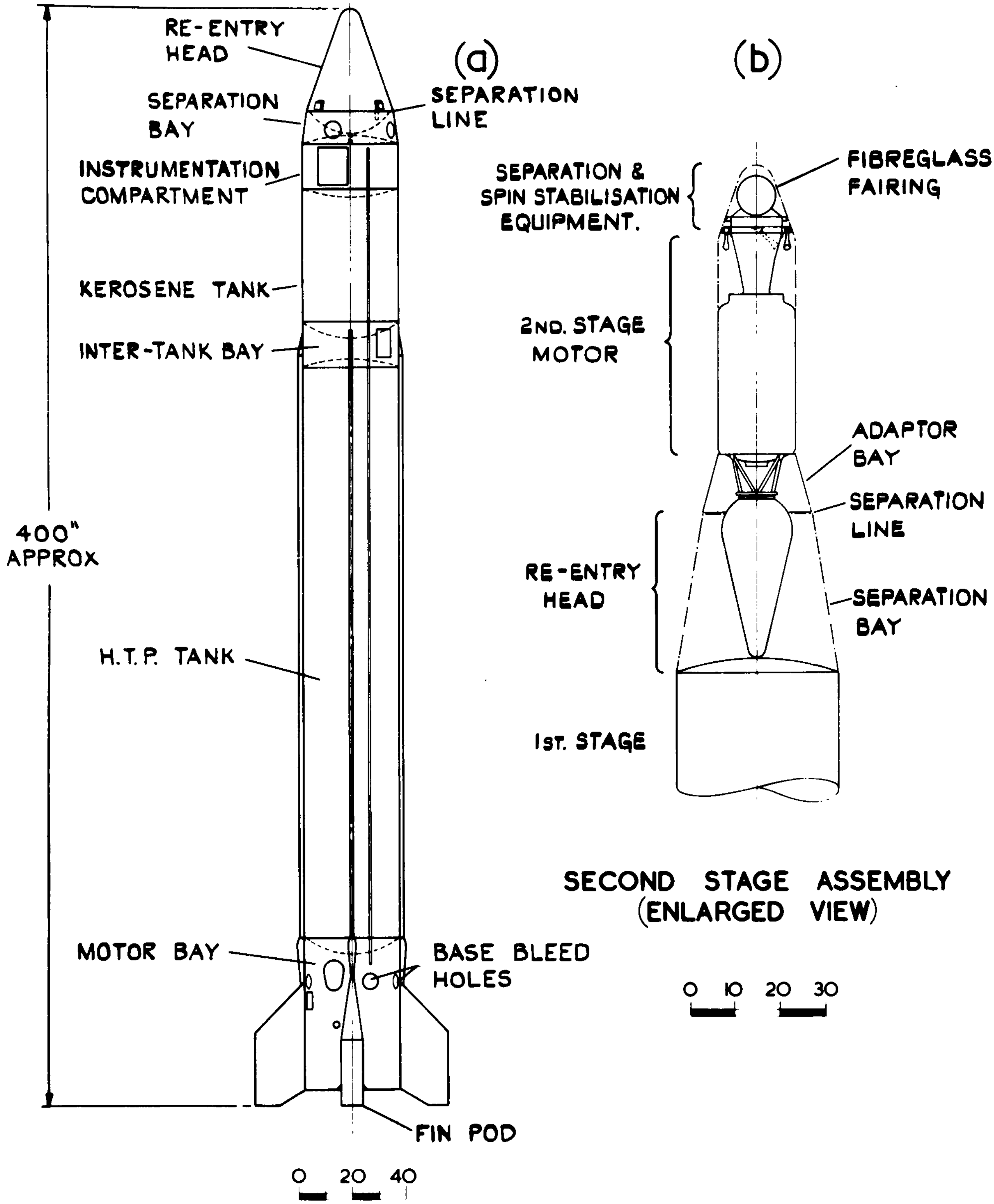
13	H. W. B. Gordon	Proving trial of the Black Knight vehicle for re-entry physics experiments. R.A.E. Tech. Note No. Space 49 Oct. 1963
14	B. Burgess I. L. Jones	H.F. radar observations of Black Knight during its passage through the ionosphere. R.A.E. Tech. Note No. Rad.784 Aug. 1960



SINGLE STAGE VEHICLE

SECOND STAGE ASSEMBLY (ENLARGED VIEW)

FIG. 1 BLACK KNIGHT CONFIGURATION

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Neg. No. C1603

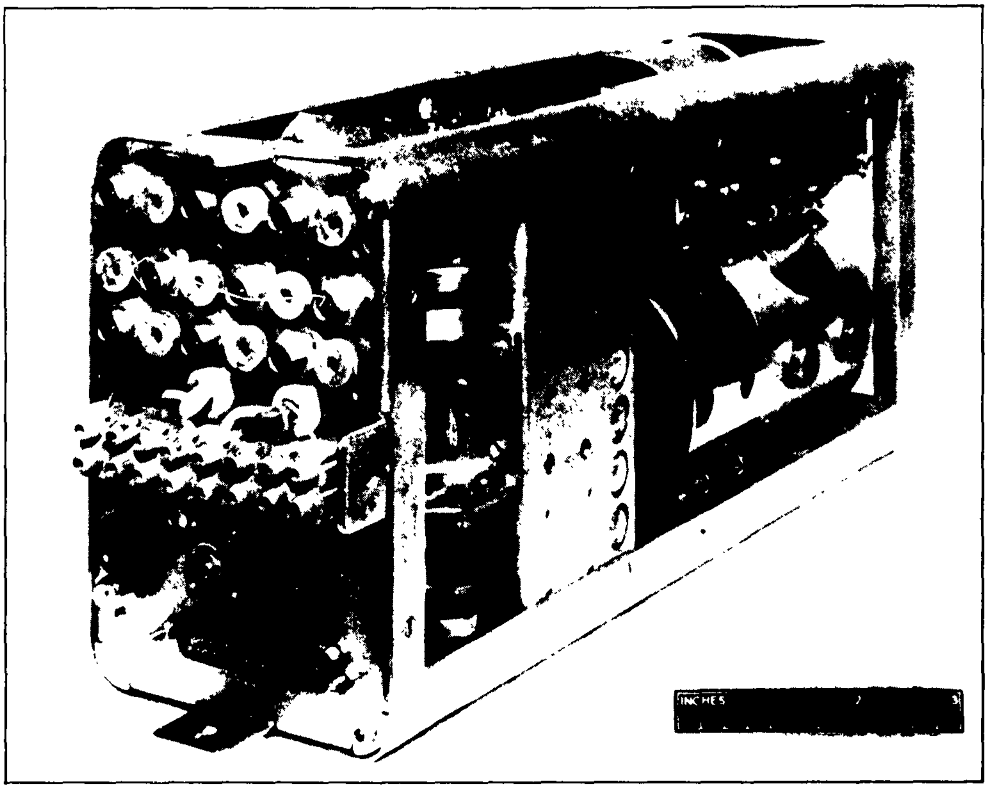


Fig.2 465 Mc/s telemetry unit

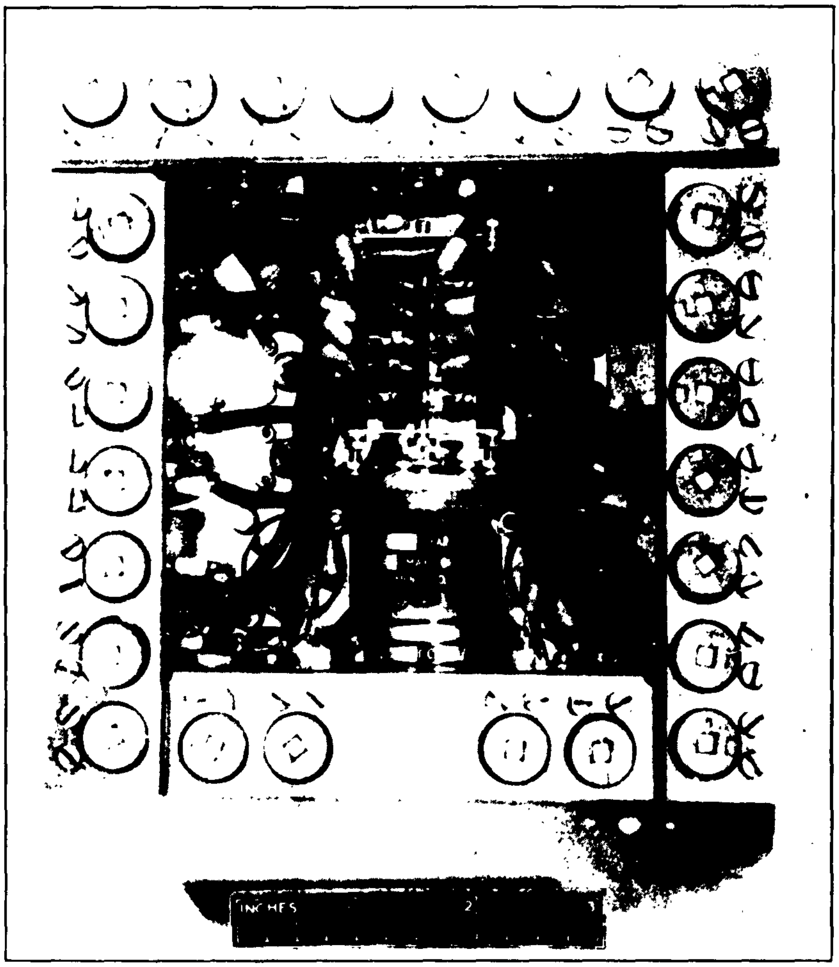


Fig.3 Sub-commutation unit for inductive transducers

CONFIDENTIAL

T.R. 66019

Fig.4 Main body telemetry aerial (465 Mc/s)

T.R. 66019

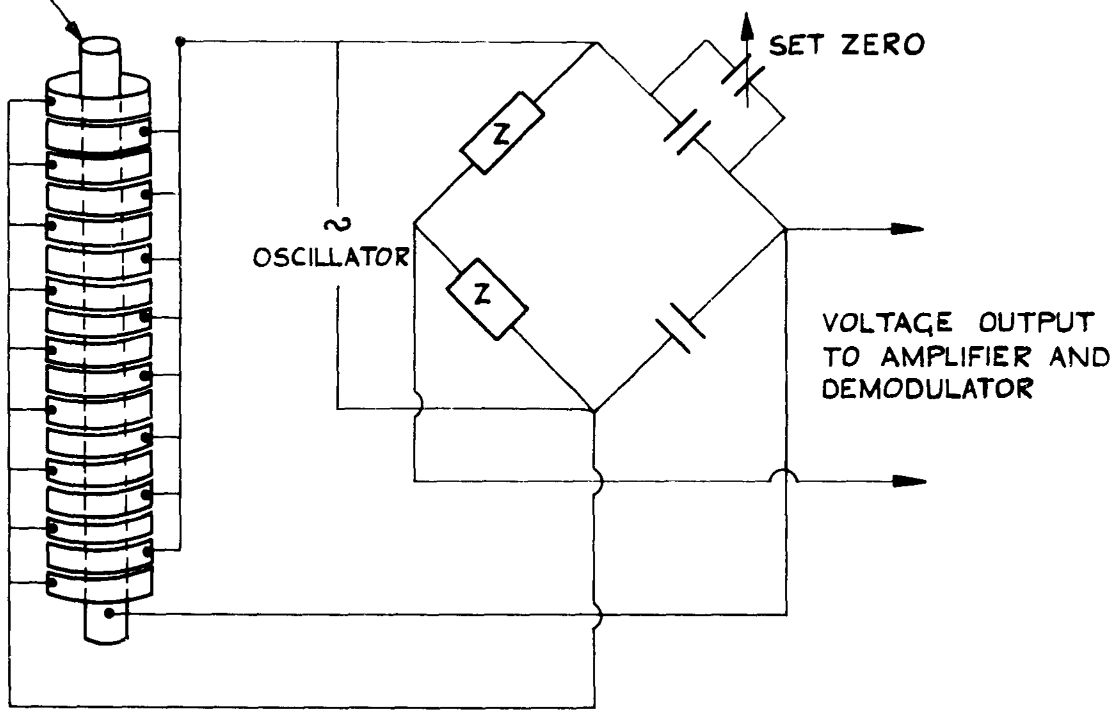
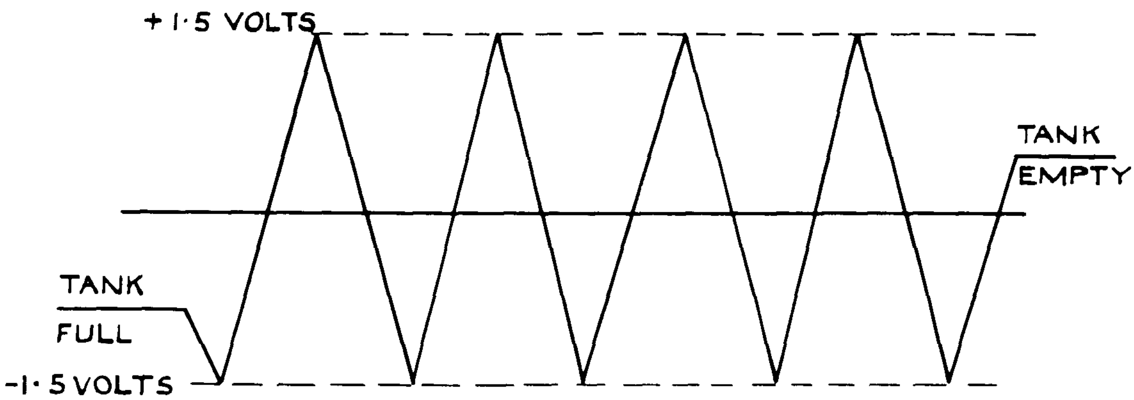


DIAGRAM OF KEROSENE LEVEL SENSOR



TYPICAL FORM OF RECORD

FIG. 5 KEROSENE LEVEL SENSOR

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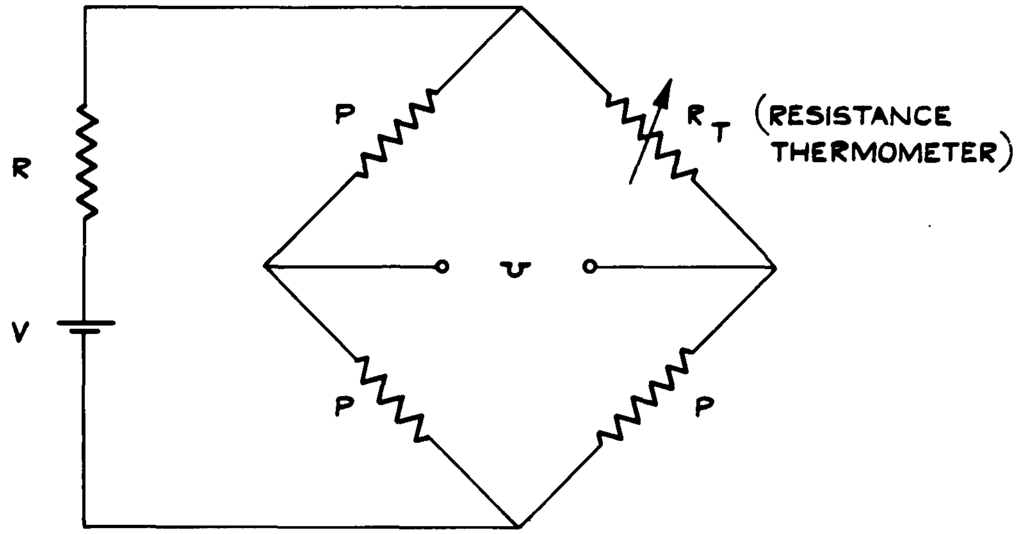


FIG. 6 RESISTANCE THERMOMETER BRIDGE CIRCUIT

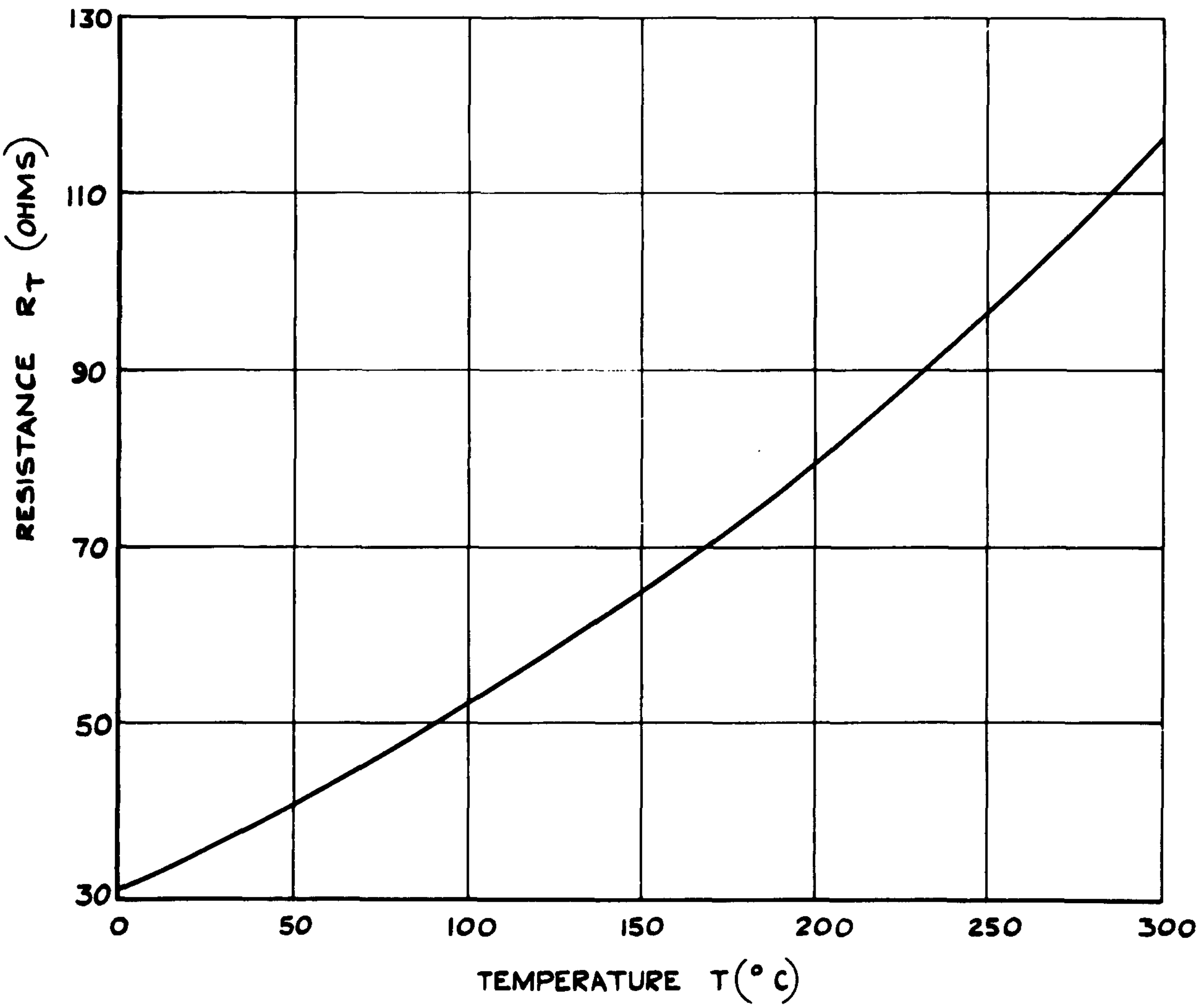
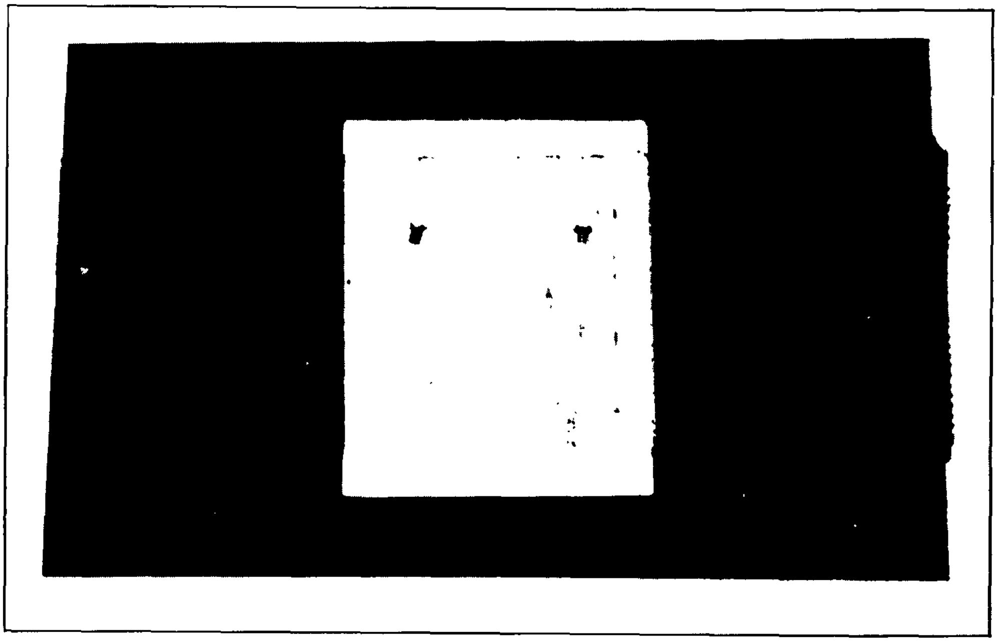


FIG. 7 RESISTANCE THERMOMETER CHARACTERISTIC



I inch

Fig.8 Skin thermometer

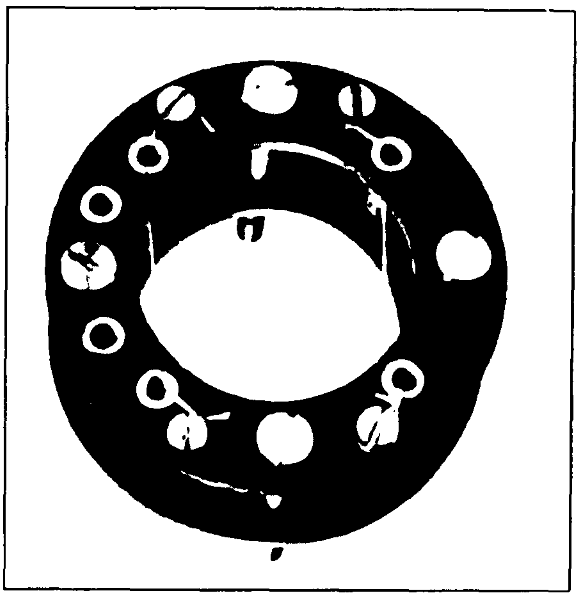


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Fig.9 Air thermometer

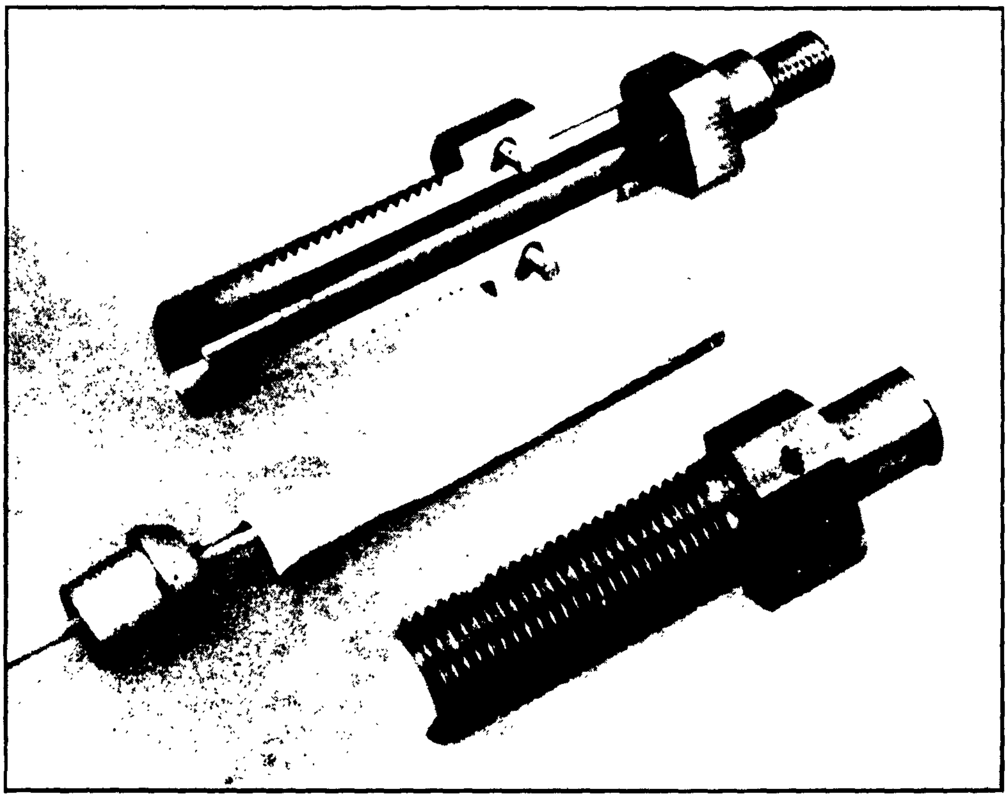


Fig.10 Explosive bolt thermometer

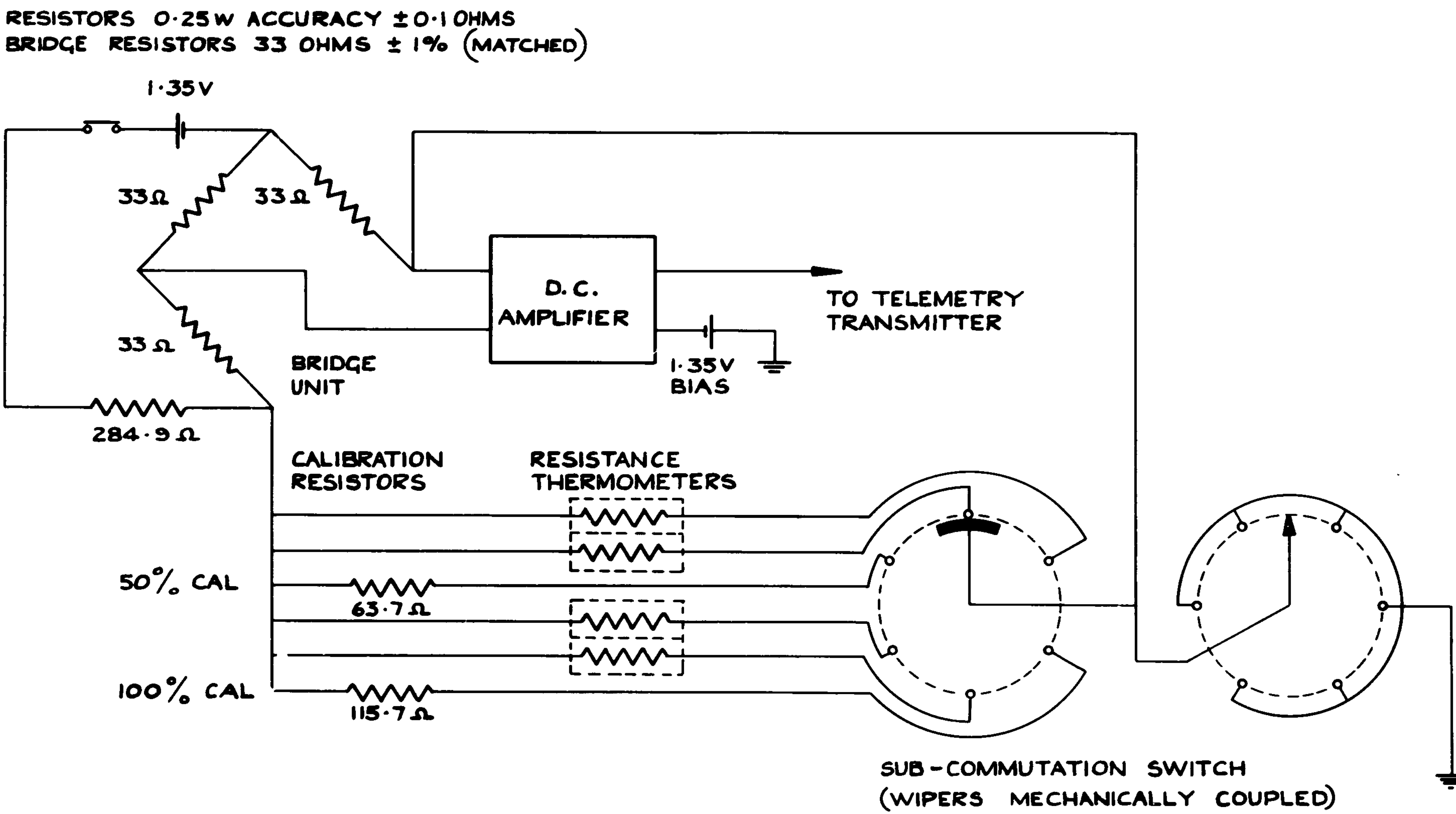


FIG.11 TYPICAL RESISTANCE THERMOMETER CHANNEL (RANGE 10 – 300°C)

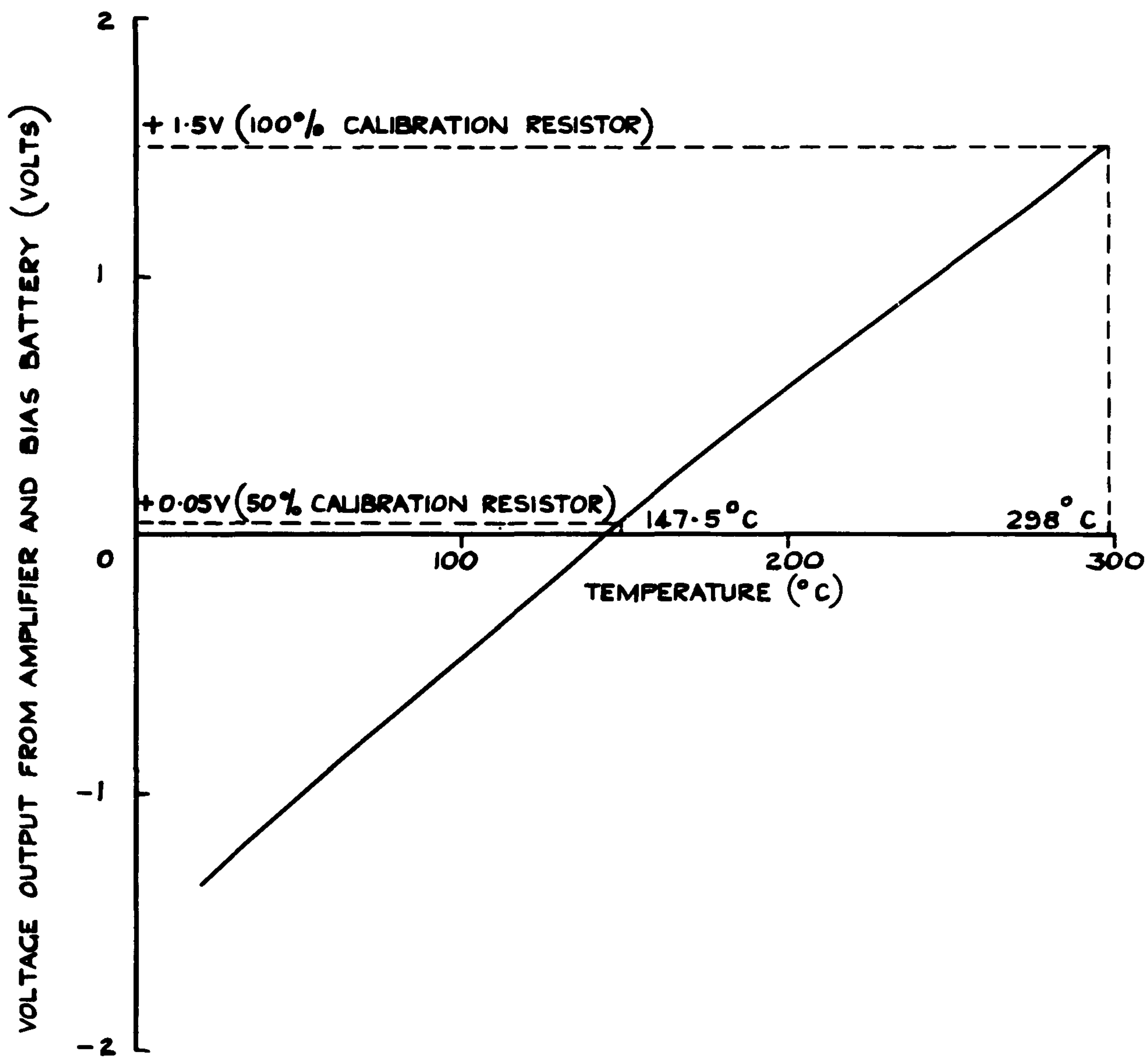


FIG.12 TYPICAL CHARACTERISTIC OF A RESISTANCE THERMOMETER CHANNEL (RANGE 10 - 300°C)

NOTE

INDUCTANCE L_9 IS ADJUSTABLE OVER THE RANGE 8 mh TO 20 mh (USED TO SET VOLTAGE OUTPUT FROM BRIDGE)

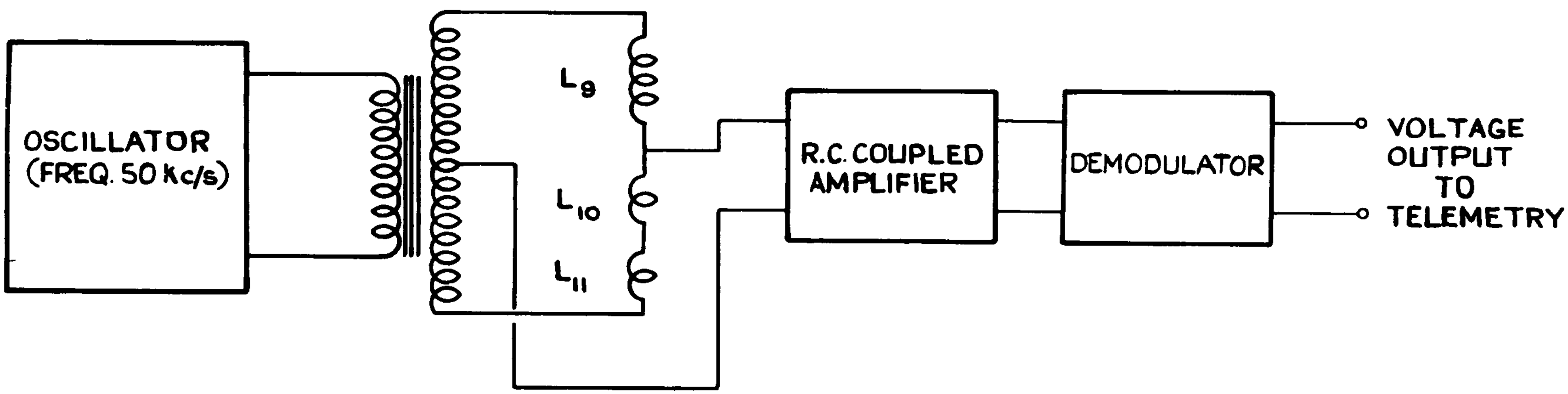
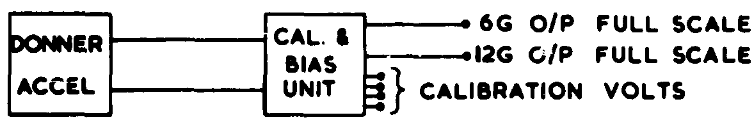
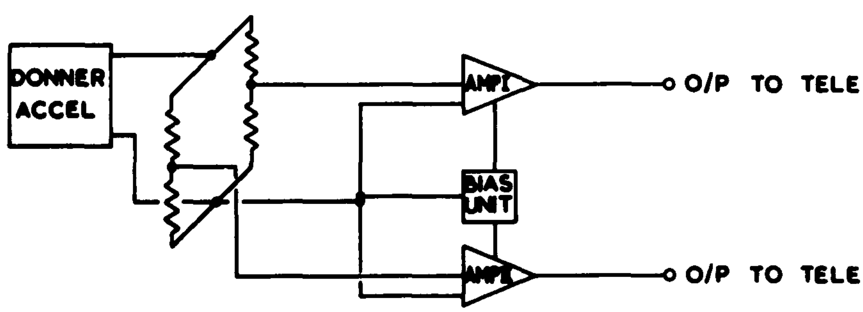


FIG. 13 SCHEMATIC DIAGRAM OF FLAP VALVE MONITOR

DONNER ACCELEROMETER



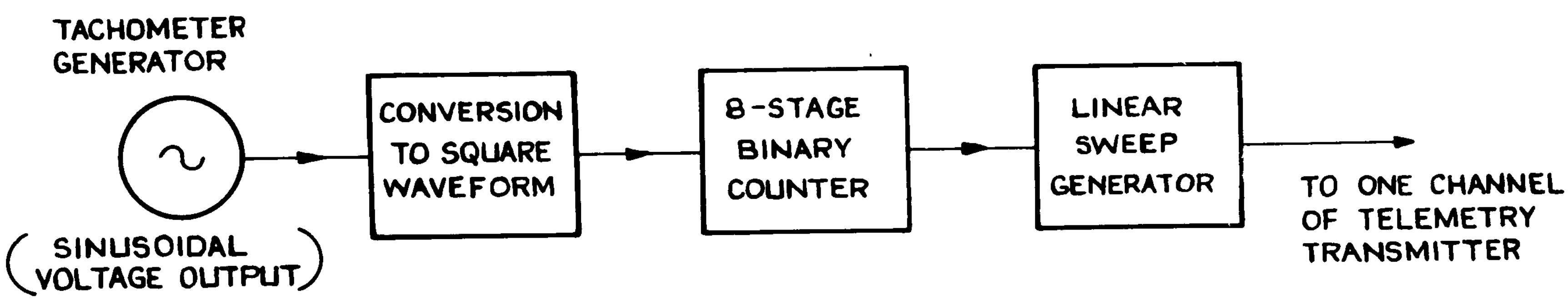
SYSTEM A



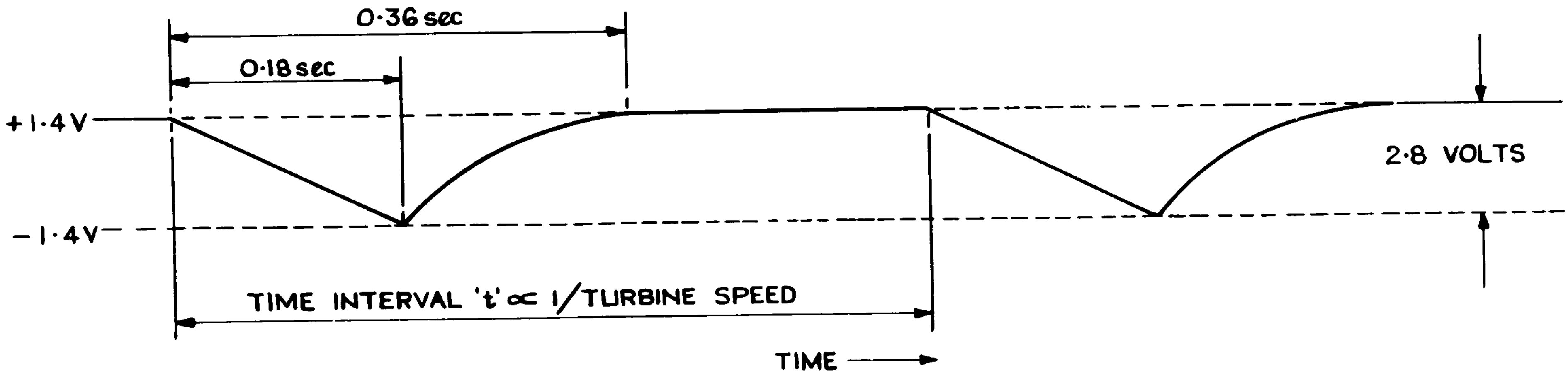
SYSTEM B

Fig.14 Donner accelerometer systems

T.R. 66019



BLOCK DIAGRAM OF SYSTEM



VOLTAGE OUTPUT TO TELEMETRY

FIG. 15 TURBINE SPEED MONITOR UNIT

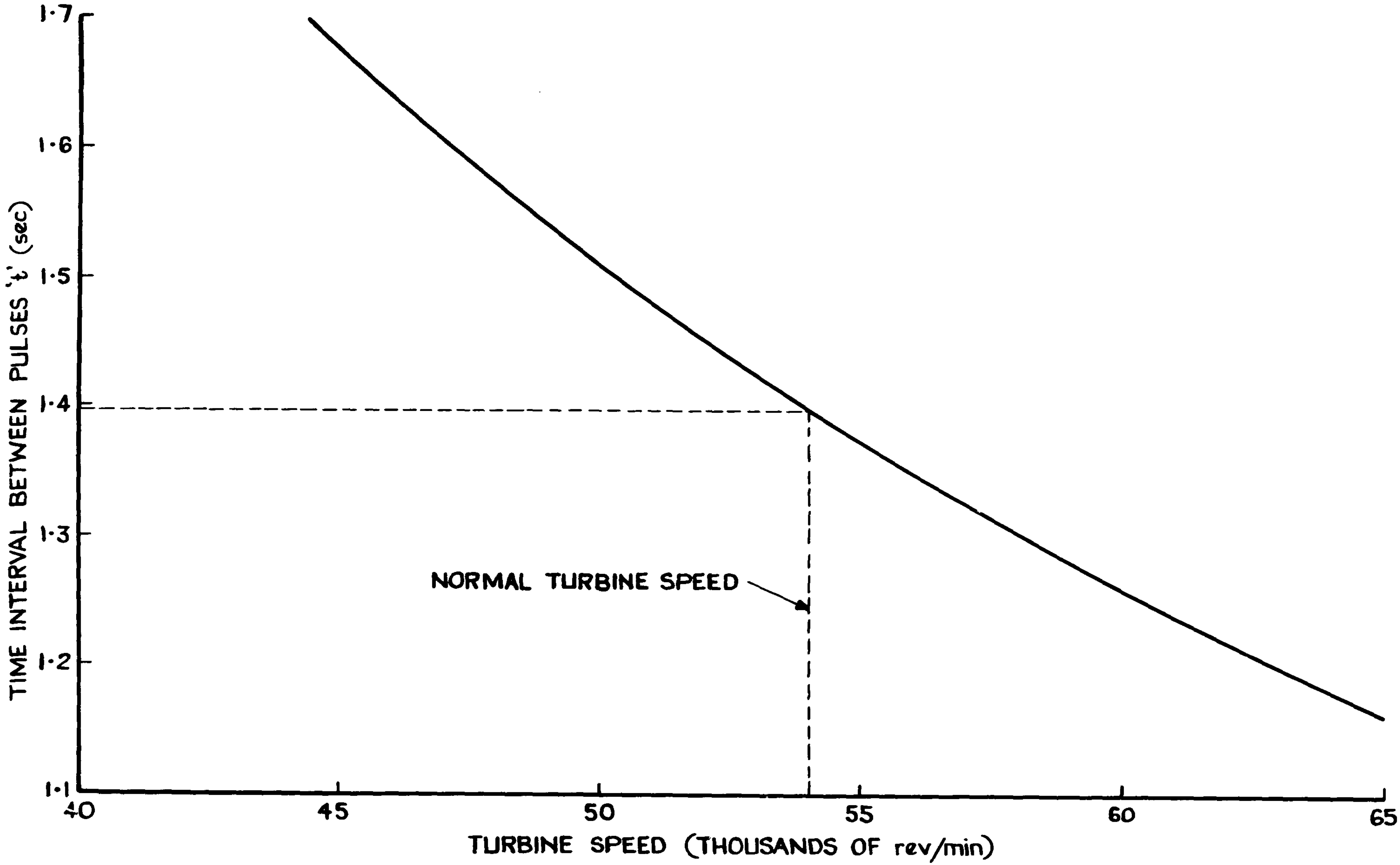


FIG. 16 TURBINE SPEED MONITOR CHARACTERISTIC

Fig.17

004 - 900045

PIN	ITEM	PIN	ITEM	PIN	ITEM
A	-	F	-4·05v	M	INPUT
B	+6·5v	H	-1·35v	N	INPUT
C	OUTPUT +	J	-2·7v	P	-
D	OUTPUT	K	-8·1v	R	-
E	-6·5v	L	COMMON +		

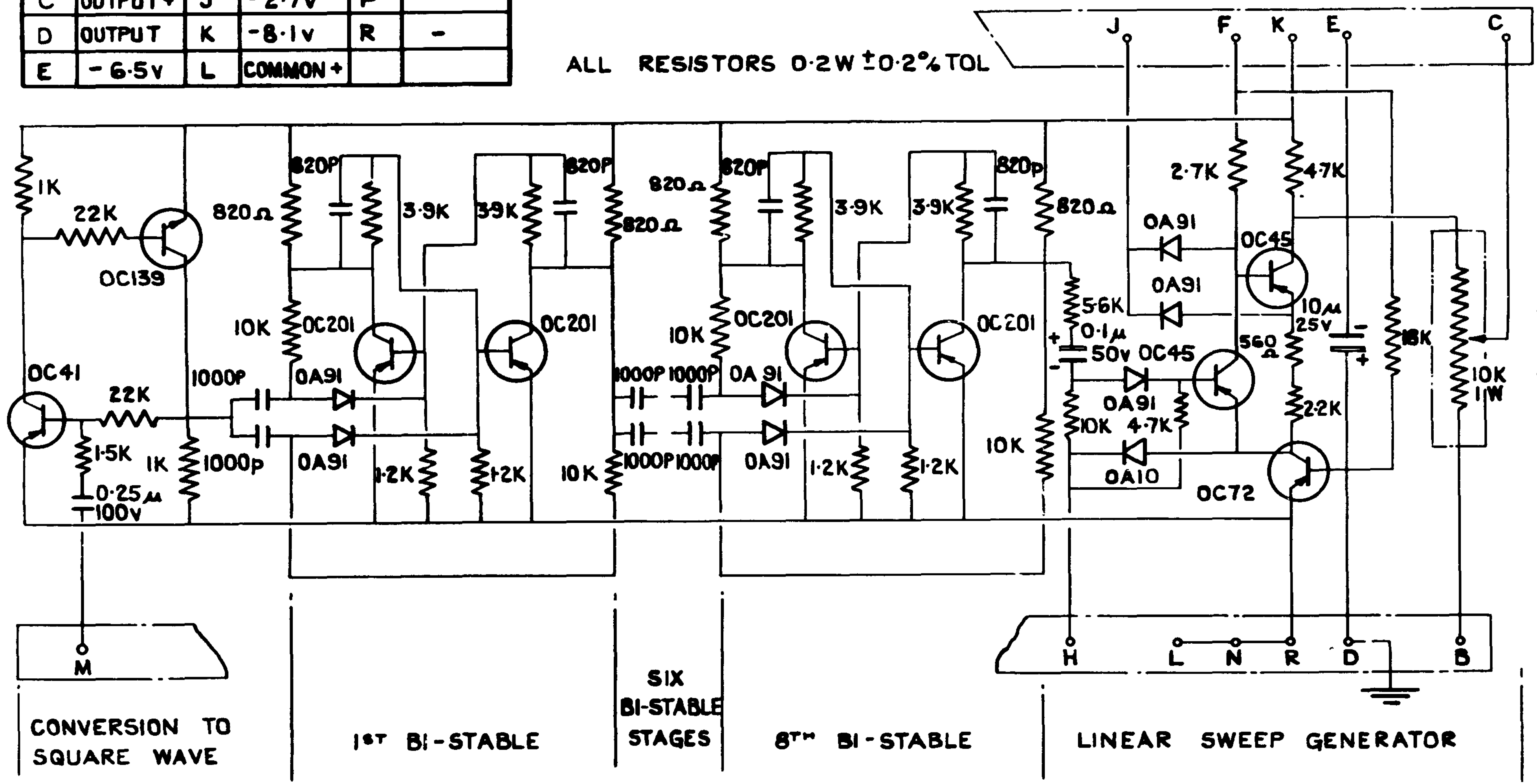


FIG. 17 CIRCUIT DIAGRAM OF TURBINE SPEED MONITOR UNIT

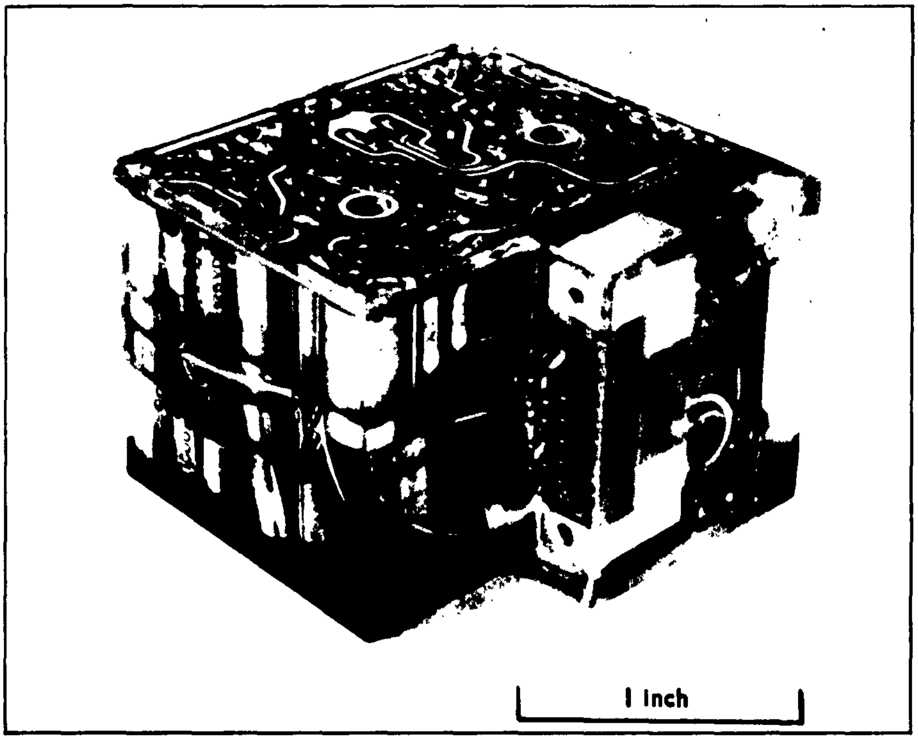


Fig.18 Turbine speed monitor unit

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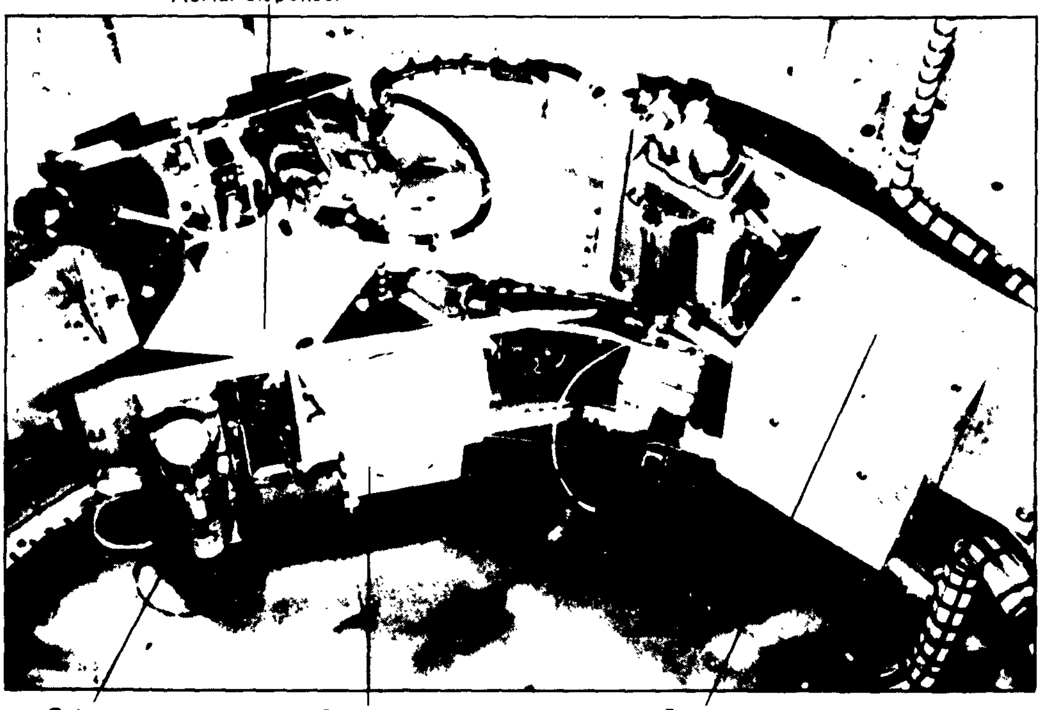
Aerial dispenser



Geiger counter

Counting electronics

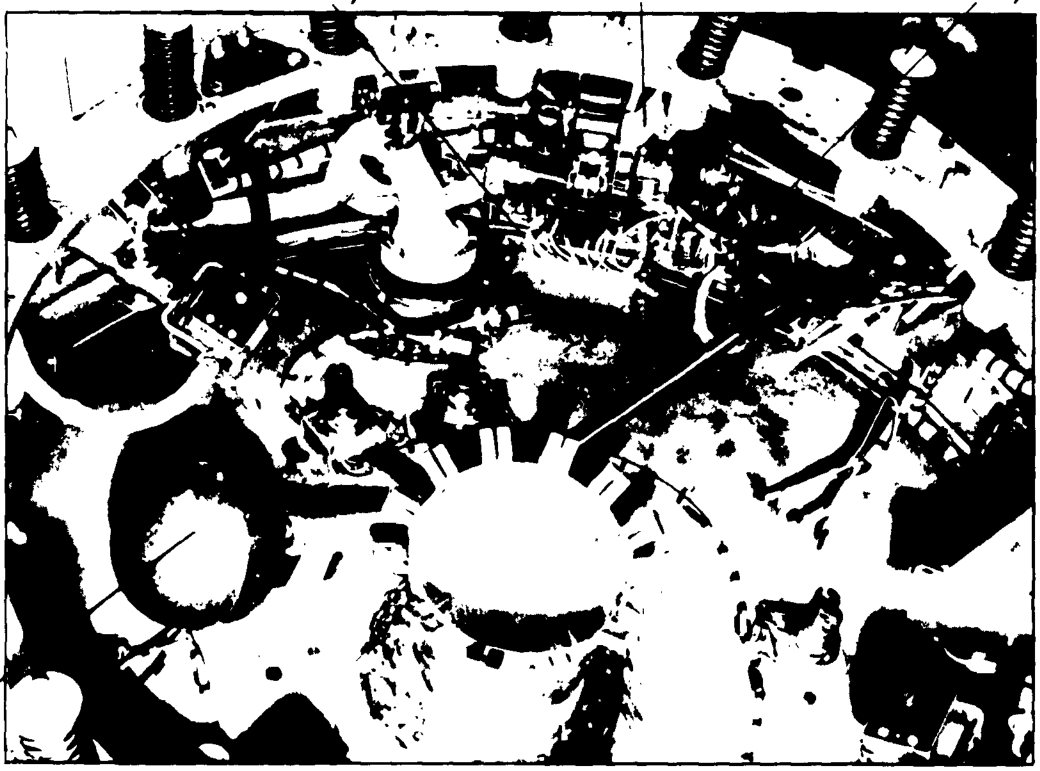
Receiver unit

Fig.19 Bk. 17 geiger counter and radio noise installation

Electronic analyser unit

Changeover switch and timer

Swinging arm assembly



Ion probe

Fig.20 Bk. 13 positive ion mass spectrometer installation

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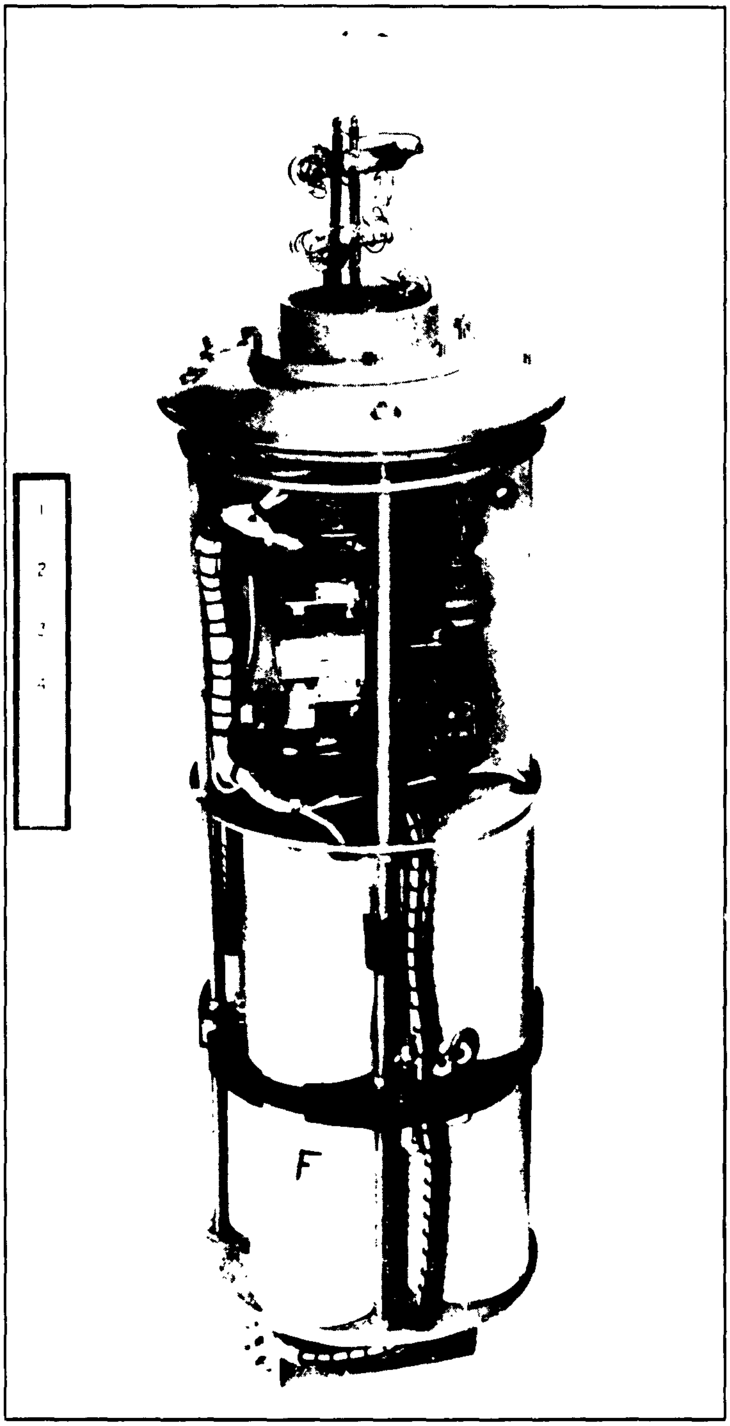

Fig.21 Electronic flash unit (Cover removed)

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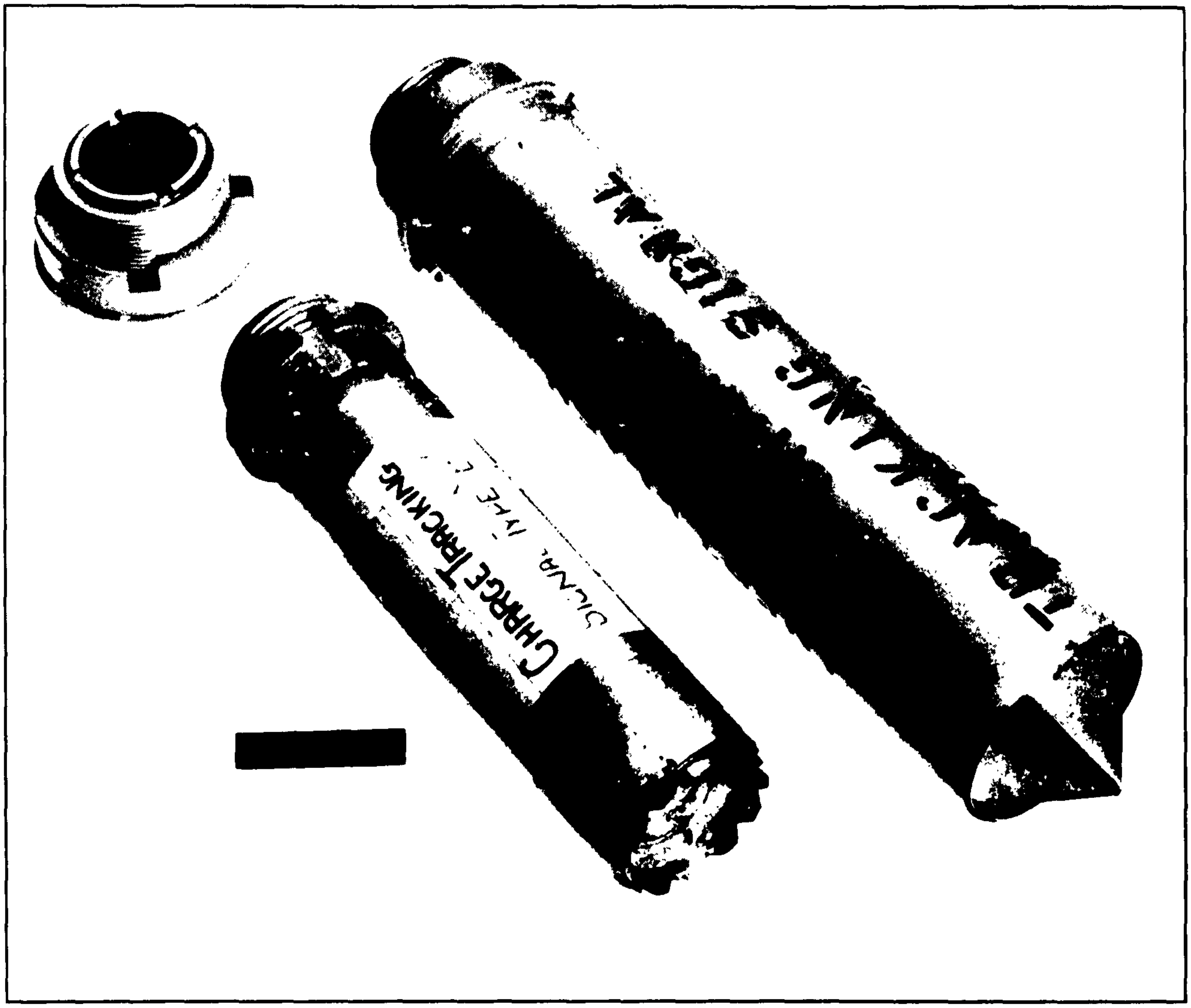

Fig.22 Pyrotechnic flash units (Type A and B)

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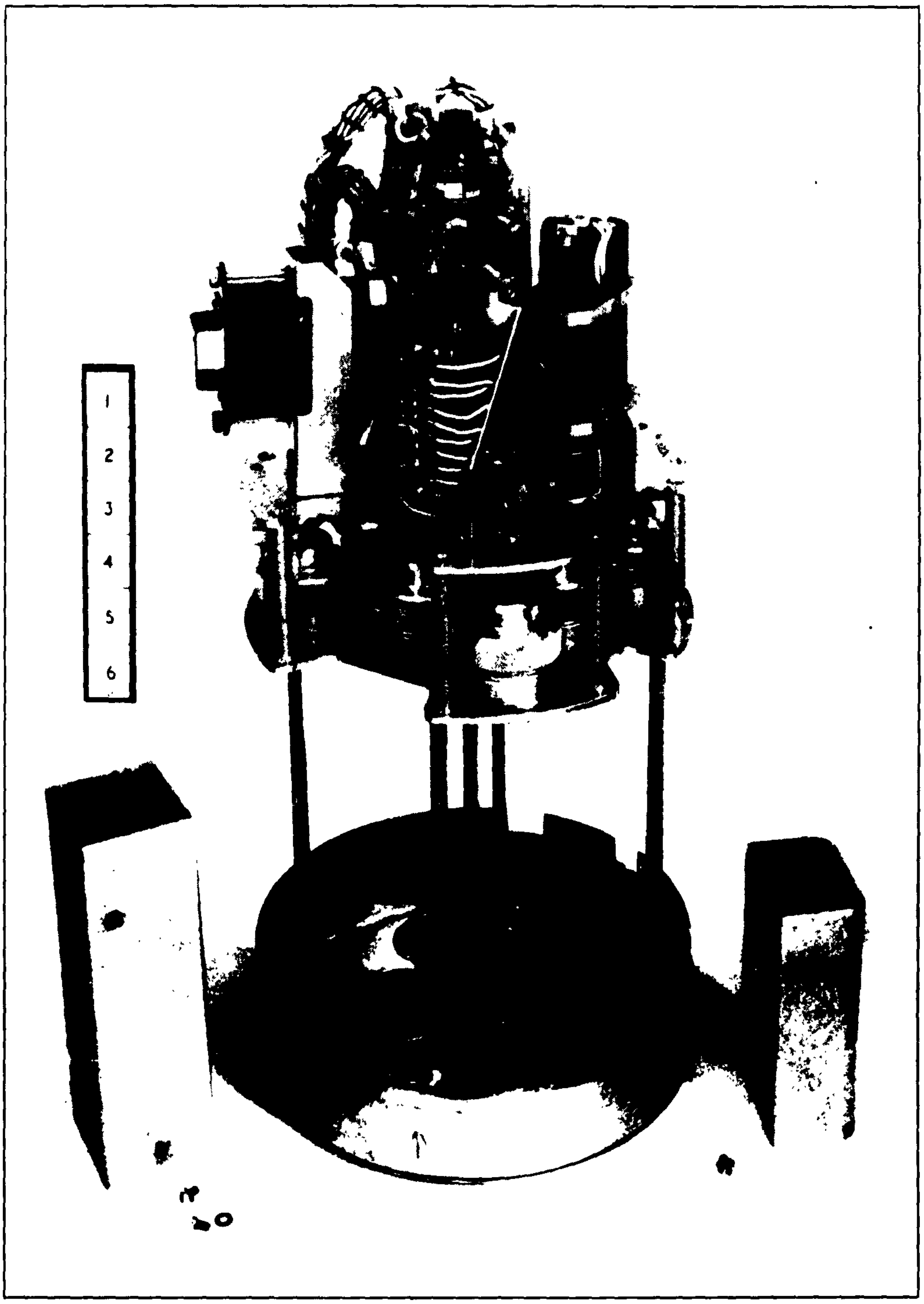

Fig.23 Pyrotechnic flash unit

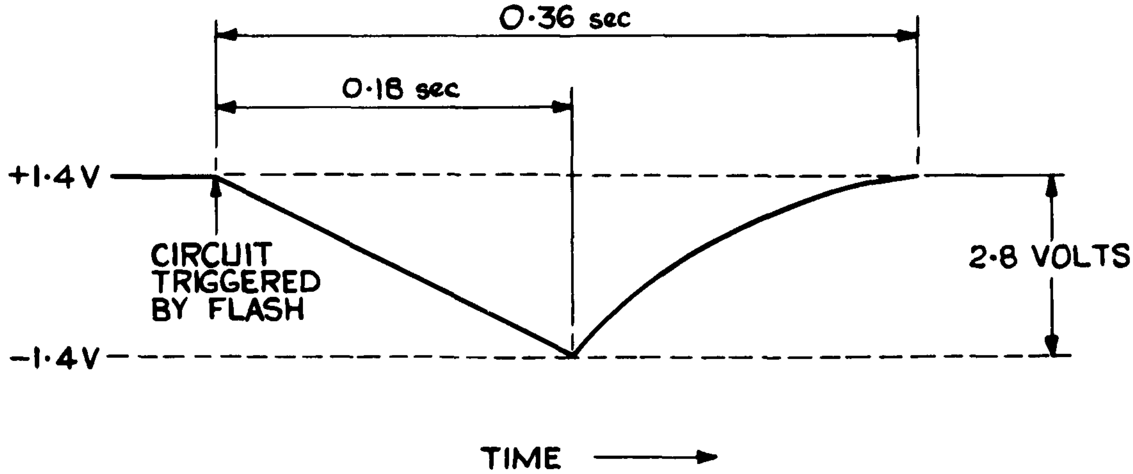

FIG. 24 VOLTAGE OUTPUT FROM FLASH DETECTOR

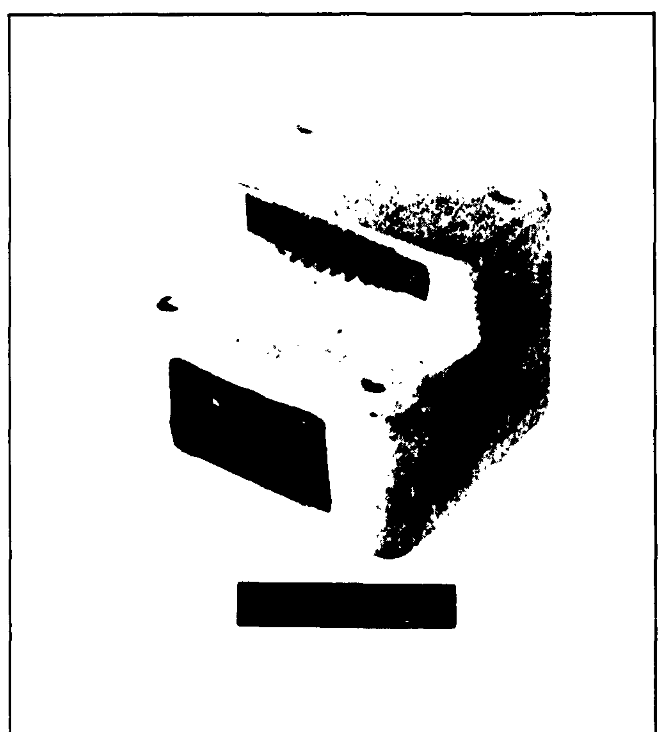

FIG. 25 FLASH DETECTOR UNIT

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Royal Aircraft Establishment Technical Report 66019 — January 1966

Details are given of the various instrumentation systems used in the main body of Black Knight test vehicles. Although existing guided weapon transducers were used for some measurements, emphasis is placed on the many special techniques which were developed specifically for this application. A brief description of optical tracking aids fitted to the rockets and an outline of the Upper-Atmosphere Research programme carried out is also included.

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